SATELLITE-TRACKING AND EARTH DYNAMICS

RESEARCH PROGRAMS

Grant Number NGR 09-015-002

Semiannual Progress Report No. 45

1 July to 31 December 1981

Prepared for

National Aeronautics and Space Administration
Washington, D.C. 20546

April 1982

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
Center for Astrophysics

The NASA Technical Officer for this grant is Mr. David L. Townley, Code TN-1, Network Operations, Office of Space Tracking and Data Systems, NASA Headquarters, Washington, D.C. 20546.

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TABLE OF CONTENTS

SATELLITE TRACKING RESEARCH PROGRAM IN SOLID-EARTH GEOPHYSICS

Semiannual Progress Report No. 45

1. INTRODUCTION AND SUMMARY

This report describes the activities carried out by the Smithsonian Astrophysical Observatory (SAO) for the National Aeronautics and Space Administration (NASA) under Grant NGR 09-015-002 during the period 1 July to 31 December 1981. Work on geodesy and geophysics and the upper atmosphere are currently funded separately from this grant, although that research is still maintained as part of a total integrated program at the Observatory. Reports related to this are included in Appendix A.

The SAO lasers in Arequipa and Orroral Valley were in routine operation during the reporting period. As a part of laser upgrading, however, hardware tests were conducted at Mt. Hopkins during the reporting period. The SAO stations obtained a total of 53,420 quick-look range observations on 2,056 passes in the six months. In addition, routine participation by cooperating networks contributed greatly to the success of ongoing tracking campaigns. Data were acquired from Helwan, Metsahovi, San Fernando, Kootwijk, Wettzell and Grasse.

The Network continued to track LAGEOS at highest priority for polar motion and earth rotation studies, and for other geophysical investigations, including crustal dynamics, earth and ocean tides, and the general development of precision orbit determination. The network performed regular tracking of several other retroreflector satellites including GEOS-1, GEOS-3, BE-C, and Starlette for refined determinations of station coordinates and the earth's gravity field and for studies of solid earth dynamics.

A major program in laser upgrading continued during this period to improve ranging accuracy and data yield. This program includes 1) an increase in pulse repetition rate from 8 ppm to 30 ppm, 2) a reduction in laser pulse width from 6 nsec to 2-3 nsec, 3) improvements in the photoreceiver and the electronics to improve daylight ranging, and 4) an analog pulse detection system to improve range noise and accuracy.

The prototype version of the hardware and software were completed in Cambridge and then installed and tested at Mt. Hopkins. The hardware successfully operates at the 30ppm rate and the new pulse chopper provides 3 nsec pulses. Software currently limits operation to 20ppm; subsequent versions of the laser control program scheduled to be ready in early 1982 will accommodate the higher rate. Ground tests at Mt. Hopkins show that the systematic range errors are still in the range of 5-10 cm, with the major problems at the moment being associated with the pulse chopper electronics. Work is currently underway to address this problem. Some satellite ranging was carried out with the upgraded system in late December, but ill-formed output pulses from the pulse chopper are giving noise levels 2-3 times that expected.

All production hardware units for the upgrading in Arequipa have been built. Some small modifications based on our Mt. Hopkins experience will be carried out in early 1982. The power system modification in Arequipa has been completed and installation is now scheduled for March.

Construction and testing continues on the production units for the other stations.

Cesium standards and Omega receivers provided on long-term loan by the U.S. Coast Guard continue to function well at the field stations. With these and other timekeeping aids, the laser stations are able to maintain a timing accuracy of better than plus or minus 6 microseconds.

The communications links with Mt. Hopkins, Arizona; Arequipa, Peru; and Natal, Brazil (through 30 November), have continued to operate satisfactorily.

Data Services has provided final data to the National Space Science Data Center for the period through September 1981. Final data are now being furnished on a routine basis 60 days after the end of the acquisition month. Most of the software activity was focussed on the adaptation of the field software for the 30ppm modification and the analog pulse processor. Considerable effort was also spent on the prediction software to improve predictions for use with a reduced range gate window.

The minicomputer to VAX link in Cambridge continues to function well. The minicomputers are now routinely used as interactive terminals and as remote data-entry devices. They provide Data Services and other support groups with a remote-batch capability and facilitate the processing of quick-look data.

Serious discussions are underway with the CNR in Italy to develop a cooperating arrangement whereby the SAO laser from Natal will be relocated to a site in Italy.

2. OPERATING STATUS

The SAO laser sites in Arequipa and Orroral Valley continued routine operations throughout the six-month period. The laser in Natal was operational through 30 September. Together with the cooperating stations in Wettzell, Grasse, Kootwijk, San Fernando, Helwan and Metsahovi (see Section 3.), the laser stations obtained a total of 63,932 quick-look observations on 2,440 passes of GEOS 1, GEOS 3, BE-C, Starlette, and LAGEOS. Monthly statistics of the passes and points, by station and by satellite, are given in Table 1.

Final data statistics for the reporting period for the SAO lasers are shown in Table 2. These data have been sent to the National Space Science Data Center at Goddard Space Flight Center (GSFC).

The Mt. Hopkins site was closed for regular data taking during the reporting period. However, station activities are concentrated on upgrading and documentation.

We continue to maintain the operations reporting procedures requested by NASA by providing statistics of tracking success, weather, and maintenance on a monthly basis. Table 3 gives the six-month summary of this information.

Table 1.

Quick-look passes and points, 1 July through 31 December 1981

Station	July		August		September		October		November		December		Total	
	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points
Arequipa	319	9,367	269	7,704	259	7,015	248	6,034	196	4,143	94	1,808	1,385	36,071
Mt. Hopkins											10	369	10	369
Natal	80	1,874	89	2,201	73	1,787	CLOSED						242	5,862
Orroral Valley	73	2,382	59	1,770	94	2,852	73	1,690	24	613	96	1,911	419	11,218
Metsahovi			1	25	14	272	9	183	7	181	2	48	33	709
San Fernando					5	100	13	279	10	247	12	231	40	857
Helwan	51	892	128	5,046	22	649							201	6,587
Kootwijk	12	137	10	109	19	236	13	250	15	245	1	15	70	992
Wettzell	6	253			20	533	5	207					31	993
Grasse			5	146	3	108	1	20					9	274
TOTAL	541	14,905	561	17,001	509	13,552	362	8,663	252	5,429	215	4,382	2,440	63,932

Satellite	July		August		September		October		November		December		Total	
	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points
BE-C	105	2,295	111	2,680	60	1,262	63	1,441	49	979	19	403	407	9,060
GEOS 1	103	2,419	125	3,800	76	1,805	68	1,227	50	1,085	41	911	463	11,246
Starlette	124	3,342	112	2,986	139	3,332	90	2,046	50	875	71	1,244	586	13,821
GEOS 3	113	2,718	113	3,027	113	2,621	79	1,843	62	1,240	40	855	520	12,304
LAGEOS	96	4,131	100	4,532	121	4,532	62	2,110	41	1,251	44	969	464	17,501
TOTAL	541	14,905	561	17,001	509	13,442	362	8,663	252	5,429	215	4,382	2,440	63,932

Table 2.

Final Data Statistics
July-December 1981 Passes/Points

	BE-C		GEOS-1		STARLETTE		GEOS-3		LAGEOS		TOTAL	
	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points
Orroral Valley	-	-	185	12,423	191	7,935	152	6,219	267	25,628	795	52,205
Natal	87	1,861	155	5,823	114	2,979	169	5,147	36	818	561	16,628
Arequipa	304	9,803	349	18,738	310	12,456	394	16,907	205	10,810	1,562	68,714
TOTAL	391	11,664	689	36,984	615	23,370	715	28,273	508	37,256	2,918	137,547

Table 3.

Laser operations summary, 1 July through 31 December 1981.

Station	Passes scheduled	Passes supported	Data obtained*	Passes cancelled owing to weather**	system down	other
Natal	791 (100%)	358 (45%)	230 (58%)	394 (50%)	26 (3%)	13 (2%)
Arequipa	2,207 (100%)	1,730 (78%)	1,354 (76%)	433 (20%)	40 (2%)	4 (0%)
Orroral Valley	1,893 (100%)	613 (33%)	450 (46%)	917 (48%)	364 (19%)	5 (0%)

* Number of passes and percent of total scheduled minus passes canceled because of weather.

** Not included are passes attempted but unsuccessful because of poor weather.

3. LASER OPERATIONS AT COOPERATING AGENCIES

In addition to operating its own stations, SAO supports the operation of overseas cooperating laser stations by furnishing orbital elements for predictions, screening quick-look data, and acting as a general U.S. interface. These cooperating agencies are located in Greece, Japan, Spain, The Netherlands, France, West Germany, Egypt, Poland, and Finland. During the past six months, SAO actively supported the Centre National d'Etudes Spatiales (CNES) Starlette program with routine laser tracking, providing CNES with orbital elements to sustain its tracking operation.

Although the laser systems in Dodaira, Japan and Athens, Greece did not furnish data during this reporting period, they have furnished SAO with data for many years. These data are screened weekly by SAO, and predictions are generated from orbital elements supplied by SAO. Work continues in both lasers to upgrade the systems and overcome technical problems in attempting to reach modes of operation consistent with current program needs. Both systems are operated by local agencies at no cost to NASA. Both have operated as an integral part of the SAO laser tracking network, responding to the routine priorities and schedules arranged by SAO headquarters.

SAO also has close working arrangements with the Institute fur Angewandte Geodasie in the Federal Republic of Germany and the Technische Hogeschool Delft in the Netherlands. The IFAG satellite-ranging system in Wettzell has been tracking LAGEOS and other laser retroreflector satellites with its short-pulse neodymium Yag mode-locked laser system which has consistently demonstrated range-noise performance of 2 to 4 cm. The Technische Hogeschool has an operating laser system at Kootwijk which is providing tracking data on LAGEOS and other retroreflector satellites with an estimated accuracy of 15 cm.

In addition to the above mentioned stations, the laser at Metsahovi, Finland which is operated by Helsinki University of Technology, Espoo, Finland and the Finnish Geodetic Institute, Helsinki, Finland, has also provided LAGEOS and other satellite tracking data during the past year. The data quality is a bit lower than that in Germany and Holland, but the system in Finland is evolving quite rapidly.

These lasers are providing a significant level of high quality tracking data on LAGEOS and the low orbiting satellites on a routine basis. During FY 1982, the laser stations in Borowiec, Poland and Shanghai, China also provided some data to the Network. Both stations are using SAO orbital elements for predictions and both have been provided with some technical and operational assistance by SAO.

SAO has provided these groups with laser pointing-prediction software plus technical support during system development. SAO has also helped coordinate their operational activities and provides orbital elements for predictions and screens their data on a routine basis. It is anticipated that these groups will continue to aggressively support the LAGEOS and Crustal Dynamics Programs.

The close liaison between SAO and CNES continued in FY 1981. During the past year, SAO actively supported the CNES Starlette program with routine laser tracking, as well as provided CNES with orbital elements to sustain its tracking operation. Under a joint cooperative arrangement among SAO, CNES, and the Instituto y Observatorio de Marina, a CNES laser is in routine operation at the SAO camera site in San Fernando, Spain. This laser is tracking several retroreflector satellites, including Geos 3 and Starlette, and furnishes SAO with quick-look data. SAO provides communications and timing services to the laser operation. SAO plans to continue this support in FY 1982. The CNES laser system at Grasse, France also provided data to the SAO network.

Since 1977, a cooperative laser tracking program with the Soviet Academy of Science, the Technical University of Prague, Czechoslovakia, the Helwan Observatory in Egypt, and SAO has been underway at Helwan, Egypt. For this program, the Soviet Union and the Czechoslovakians provide and maintain a laser tracking system at Helwan, the Helwan Observatory furnishes personnel to operate the system, and SAO supplies technical consultation, a station clock, and partial operating support through the Smithsonian Excess Currency program. The data are routinely screened and validated by SAO. Under this program, the station has been supplying range data at no cost to NASA. During the past two fiscal years, the system was upgraded on site with a new short-pulse laser, giving an improved range

accuracy estimated at 25 cm. Improved software and more rugged optics have also been incorporated in the system. Efforts continue to further improve range accuracy and data yield.

4. SATELLITE OBSERVING CAMPAIGNS

The laser tracking network continued its program of data acquisition, with particular emphasis on follow-up support for the preliminary MERIT Campaign. In addition, satellite observations were made to:

A. Support the scientific and orbital maintenance requirements for LAGEOS and the Crustal Dynamics Program.

B. Support the study of earth body and ocean tides, seasonal and other variations in the earth's gravity field, and the investigation of polar motion.

C. Provide data for improving the accuracy of station coordinates and the gravity-field model, which are necessary for LAGEOS and other geophysics programs.

D. Support the tracking campaign for Starlette in conjunction with CNES.

With the success of the preliminary MERIT Campaign in 1980, work continues on a routine but informal interim basis to keep continuous tracking coverage on LAGEOS and Starlette and to continue the routine calculation of pole position from all available quick-look data. This is particularly important for all investigations involving long period effects such as the annual and Chandler effects.

5. OPERATIONS AND MAINTENANCE ENGINEERING

The Engineering Group of the Experimental Geophysics Department provides the daily hardware and systems support necessary to maintain routine network operations. It is also responsible for the system modifications and improvements required for new programs.

5.1 Laser and Photoreceiver

During the last week of July, the compressor in the laser cooling unit at Orroral Valley failed and could not be repaired. As a result, the laser was not operational in late July. A direct replacement unit for operation at 60 Hz could not be obtained from local manufacturers and a temporary replacement was made using a 50 Hz unit. This unit eventually failed and an arrangement was made with NATMAP at Orroral Valley to borrow their cooling unit, until a direct replacement unit could be purchased and shipped.

The replacement compressor was shipped in September and is now on site for installation in early 1982. Premature failure of a number of flash lamps at Orroral Valley required operation without the amplifier rod for several days in September. Replacements were shipped from Mt. Hopkins and Cambridge. The bad flashlamps are being returned to Cambridge for examination. To determine if there were better and more reliable flash lamps available we have purchased lamps from an alternative source. A series of tests making comparisons on lamp lifetimes are presently ongoing.

We have also been having some difficulty with the reliability of thin film polarizers recently purchased from OCLI (California) and Transworld Optics (New York). Tests at Arequipa showed early coating failures.

Two off the shelf polarizers from a third manufacturer, CVI (New Mexico), were purchased in December for testing in Arequipa during the upgrade installation.

5.2 Pulse Processing

During the past year, no fundamental changes were made to the pulse processing detection systems. The systems operated with little of no problem. The Arequipa station experienced problems with the Nanofast Counter which was out of service for 5-6 days in February while repairs were being made on site. In the interim the Eldorado Counter was used in its place.

As the manufacturer of the WD 2000 waveform digitizer no longer supports the repair of this unit, the burden now falls on the equipment user. A special purpose test module was built in FY 1979 for the testing, alignment and fault diagnosis of critical circuit boards within the digitizer. This repair station has been maintained and operated at headquarters for the repair of the WD 2000 boards.

5.3 Minicomputers

The field minicomputers continue to perform all data processing and control functions required by the laser tracking systems. Some operational problems were experienced, however.

An error, first thought to be hardware, occurred both in Arequipa and Natal. The error, finally traced to the lunar perturbation software overlay, was avoided by an elements epoch change. Since this overlay is being re-written, time has not been devoted to correcting this one-time problem.

A problem with the Natal system, which was causing occasional non-fatal single memory cell changes, appears to have been solved by memory module interchange.

During this reporting period, the non-fatal intermittent problem with the Orrcral system became more acute. This required the dispatch of spare memory from Mt. Hopkins and a spare central processing unit from Headquarters to isolate the problem. The replacement computer boards

provided some assistance but the station is still experiencing intermittent non-fatal errors. It was our intent to send the computer system from Natal to Orroral after checkout in Cambridge. The computer from Australia was then to be examined and repaired in Cambridge. With the impending closure of the Orroral station, no action has been taken in this regard.

At headquarters intermittent failures on minicomputer System B were finally solved by: 1) replacement of two memory boards; 2) rewiring the backplane interrupt chain, and 3) repairing the power supply. Failed memory modules have either been sent out to a repair vendor or are being repaired in-house.

The two Decwriters for the Headquarters A and B systems arrived and were installed in November.

The communications minicomputer continues to assist communications personnel in the preparation, storage, and archiving of data messages. Since the implementation of the data links, laser data have been routinely transferred to and from the VAX with a high degree of reliability. This computer is equipped with Linc-tape units, a keyboard/printer, a paper tape reader and perforator, and a Lexiscope display. The mainframe and all peripherals have been operating routinely during FY 1981.

Communications changes to facilitate transfer to ASCII coding, digital cassette and miniterm usage in place of paper tape on the radio link, and investigation of error correction and detection coding schemes for more efficient data communications are being pursued.

A nine-track tape drive for one of the Cambridge based minicomputers was received. Work began to interface this device to the minicomputers and thereby eliminate a large part of the formatting and data transfer problems that are now experienced with the seven-track drive.

Studies continue on the feasibility of utilizing a minicomputer-radio link communications path as well as further automation of the Communications Center. These studies are aimed at increasing current system flexibility and reliability as well as accommodating any further expansion.

5.4 Timekeeping

During FY 1981, timekeeping systems for the SAO tracking network have maintained epoch time traceable to UTC (U.S. Naval Observatory) with an accuracy of better than plus or minus 6 microseconds, except for Egypt, which maintains time to plus or minus 50 microseconds (see Table 4). Each of the NASA supported SAO tracking sites was equipped with a broad-based timing system comprised of dual parallel timing channels. Cesium oscillators, backed up by rubidium oscillators, offer a stable time base for each channel. Redundant time accumulators guard against time discontinuities, and redundant VLF/OMEGA receivers provide a reliable backup and frequency reference for the system.

A 10 microsecond jump in the main timing channel occurred in Peru during July. Clocks were time adjusted to make up for the jump.

NASA portable clock comparisons were provided for the tracking stations in Natal, Arequipa and Orroral Valley during the reporting period.

Low signal levels for the Loran receiving system in Egypt have been causing difficulties for some time. Antenna cables, found damaged were repaired during January and the unit is now functioning well. An epoch measurement with Loran has shown that the local cesium is drifting at an 18 microsecond/month rate.

A clock trip was requested for the Egypt site after a repair of their Loran equipment. Earlier clock trip data from Egypt were requested for evaluation before a decision is made.

Clock Selector Panels for the ECCo clock system have been completed. Documentation is being finalized. These units should facilitate data taking as the sequence of switch positions on the selector panel corresponds to the timing log data sequence.

The cesium oscillator and Omega monitor from Natal are being returned to SAO. Current plans are to return this equipment to the United States Coast Guard.

The Omega monitor receiver based at headquarters was set up for a month to aid in determining signal quality and system reliability for air navigational use at the Department of Transportation (DOT) in Cambridge, Massachusetts. The DOT was interested in studying Omega signal levels and whether the system provided continuous service. A favorable evaluation could mean expanded use of Omega for air traffic navigation.

The Austron Automatic Loran receiver and Linear Chart Recorder were evaluated for future use in the dual channel timing system.

The first Nova satellite was declared operational and daily timing data as well as data from the earlier transit system satellites is now being pursued by the U.S. Naval Observatory and referenced to their master clocks. It was a disappointment to learn the spread spectrum system was not utilized aboard the Nova satellite. Without it, better than a 2 or 3 microsecond accuracy with the system will probably not be possible.

The SAO timing engineer attended the Precise Time and Time Interval Planning Meeting at Naval Research Laboratory in Washington early in December. He presented a paper entitled "High Accuracy Omega Timekeeping". At the meeting there was much concern about the use of the full GPS capability for civilian applications. Hopefully the issue will be resolved before a large expenditure in GPS timing receivers is made.

A proposal was written to the Smithsonian Institution Office of Excess Currency (PL 480) for testing a new Austron automatic Loran receiver, obtaining epoch time from Omega transmissions, and maintaining time to an accuracy of about 4 to 6 microsecond in a remote location in India. It is in the form of an extension of a current cooperative program for research to be carried out principally at the Uttar Pradesh State Observatory in Naini Tal, in cooperation with Smithsonian Astrophysical Observatory, U. S. Coast Guard, and Austron. This work would be carried out as a test of alternative timing systems in remote locations.

Table 4

SAO NETWORK TIMEKEEPING STATUS for July thru December 1981

Definitions:

(STAT - UTC) epoch range of SAO field station main clock a positive quantity means station clock ahead of UTC as maintained by the US Naval observatory (USNO)

REDUCTION UNCERTAINTY estimated absolute error of reduced station time during the period specified. Future clock comparisons may lower this uncertainty value.

EPOCH SET UNCERTAINTY estimated epoch time transfer accuracy

LAST COMPARISON the last portable clock comparison on site Cs refers to cesium portable and Xtal to crystal portable

STATION	REDUCTION from	PERIOD thru	(STAT - UTC) RANGE microseconds	REDUCTION UNCERTAINTY <+/-microseconds	EPOCH SET UNCERTAINTY <+/-microseconds	LAST COMPARISON by	LAST COMPARISON when	COMMENTS
AUSTRALIA	Jul 1 81	Jan 1 82	3 to 20	1 to 5	1	Bend/Cs	Jun 15, 81	
except	Nov 8		13	1 sec		Bend/CS	Oct 81	
BRAZIL	Jul 1 81	Dec31 82	9 to 15	4	2	Bend/Cs	Sept 2, 81	
	Aug 26	Sept30	3 to 4	2	2			
EGYPT				50		Czech/Cs		no data received
MT HOPKINS	Dec 18	Dec 19	9 to 12	4	2	SAO/xtal	Dec 81	
PERU	Jul 1	Aug 21	-2 to 18	3 to 5	2	Bend/Cs	Aug 28	
	Aug 21	Jan 1	1 to 15	2 to 6	2			
except	Jul 25	Jul 26	2 to 12	8				

6. COMMUNICATIONS

The communications center provided voice and teletype radio links to the SAO laser field stations in Arequipa and Natal. SAO also maintains FTS service within the continental United States, and is connected with Western Union, TELEX, NASCOM and recently acquired RCA GLOBOM circuits for worldwide communications. The RCA GLOBOM circuit has been installed and operating on line since early December. We are presently sending 75-80% of our overseas traffic, formerly passed by the W. U. TELEX, on this new circuit because of the less expensive message rates. W. U. TELEX is retained, however, for domestic use and some overseas traffic. As a means of economizing, SAO closed out its AUTODIN connection; requirement for the circuit is now being fulfilled through NASA via NASCOM.

The HF communication links with Natal and Arequipa have been operated satisfactorily during the reporting period. After 30 September, communications with Natal was limited to administrative traffic while closeout activity was underway; however, the teletype equipment continually requires adjustments and continues to be the weak link in the system.

In March, the H.F. primary transmitter was found to have low power output. The V108 LF amplifier was replaced and the directional coupler was repaired during this reporting period. Normal traffic was passed on the backup transmitter. In December, the backup transmitter (TX#2) failed due to overheating, as a result of a malfunctioning room air conditioner. The air conditioner has since been repaired and the room temperature is back to normal. Three tubes and a resistor were replaced in TX#2. This transmitter is now being used at 70% of its full power. Further testing will follow as time allows before the system is brought up to 100% power output.

The primary ASR #28 TTY at Cambridge failed twice in early April. Both failures were attributed to mechanical jamming in the printer mechanism. Drive gears were replaced both times, in addition to clutch alignment and lubrication. This machine was returned to full service within a few days. A backup TTY machine was used during the repair period.

In FY 1981, an operational data link between the communications minicomputer and the VAX 11/780 was implemented to facilitate transfer of edited data into the processing files. The minicomputer is now used routinely for data-editing and data-handling aspects of the communications operations, providing considerably greater flexibility and increased speed.

During this reporting period, SAO reduced its Grant supported communications staff from 2.5 to 2 people in a program-wide effort to reduce costs.

7. DATA SERVICES AND PROGRAMMING

The Data Services Group maintains the operational and prediction cycle necessary for the efficient flow of data to and from the SAO field stations. This group screens and validates all incoming data, generates orbital elements for all satellites being tracked by the SAO laser network and cooperating stations, supplies orbital elements to SAO stations and other agencies, and furnishes SAO laser data to the NSSDC at GSFC.

7.1 Data Services

Two major areas of activity covered by Data Services are the quick-look cycle and final data processing. The quick-look phase functions on a weekly schedule, in which the SAO and cooperating foreign field stations send small subsets of their acquired data through communications channels to Cambridge. These data then form the basis for generating updated orbital elements, which are communicated back to the field stations, where they are used to compute the predictions necessary for laser satellite ranging.

The full data sets on Linc magnetic tape are mailed from the SAO laser stations to Cambridge and sent through the final data-processing cycle. This process consists of an engineering filter to assess data quality, followed by a noise filter, a time correction program and a formatter.

The quick-look functions of the Data Services operation have evolved into a stable, reliable, and smoothly running procedure. Acquisition orbits were computed and transmitted each week virtually without incident. The quality of these orbits remains very high; ephemerides are now routinely computed to the sub-10-meter level and, in the case of LAGEOS, to the 2-meter level.

In the latter half of CY 1981, the Data Services group processed 63,932 laser quick-look data points and handled 2,440 passes from the SAO and cooperating stations on GEOS 1 and 3, Starlette, BE-C, and LAGEOS. (See Tables 1, 2 and 3).

During the reporting period, the Data Services group, using LAGEOS data from the SAO and NASA laser networks as well as from certain cooperating foreign organizations, provided 5 day mean pole positions as a by-product of the routine orbital determination and data assessment activity. The pole positions are transmitted weekly to the B.I.H. in Paris as a rapid service to the world scientific community.

In CY 1981, the Data Services Group processed and sent 82,122 points in 1,856 passes of data to the NSSDC. The Data Services groups has been maintaining a 60 day turnaround on final data submission to the NSSDC. Final data from the SAO laser network from October 1981 were transmitted to the NSSDC by year's end.

SAO compiles and publishes the quick-look data catalog for satellites tracked by the laser systems. The tabulation includes all quick-look data submitted. This catalog also now contains the 5 day mean positions of the pole. This service has been found useful in the past by members of the scientific community.

As a means of economizing, SAO has re-organized internal procedures in order to carry on operations at a reduced staffing level. The Data Services staff has been reduced from 5 to 3 people. In addition, at the end of the December, the decision was made to stop tracking of two satellites: GEOS-1 (6508901) and GEOS-3 (7502701).

In September, the Observatory took delivery of a second VAX computer. All users, including the Data Services group, will be partitioned between the two machines in order to balance resources.

Operations were switched to the new VAX computer in October with no adverse impact on Data Services performance. Network operations are now benefitting from the quick response and the economies of economy-mode priorities on a lightly loaded machine.

7.2 Programming Support

SAO maintains a small staff of computer programmers who support the operation of its tracking program. In addition to routine maintenance and upgrading of the minicomputer and production processing programs, the Programming Group develops software to meet new needs and supports the Data Services Group in routine processing as necessary. The Programming Group analyzes test data for laser-system maintenance and for planning laser-system modifications to improve performance.

7.2.1 Routine Programming

During this reporting period, SAO began the development of field software for data screening. Based on the main frame software currently in use at SAO, the new program uses observed minus predicted residual as a basis for least squares data evaluation. To date, the program is working on the Nova 1200 computer using a linear screening algorithm, low order polynomial fitting, and graphic display of residuals. The package is able to handle in excess of 200 data points per fitting segment. The software currently screens data down to the 15-30 cm level. Work is underway to extend the range of the polynomial fit from 7th order to 12th order to improve the screening capability. We expect this software to be ready for the field by mid-1982.

7.2.2 Programming Support for Upgrading

In support of the laser upgrading program major changes are underway in both the field and headquarters software. These include:

<u>Field Prediction Software</u>

1. Accommodate variable operating rates from 8 to 30 ppm.

2. Include narrower range gate window.

3. Add more elaborate lunar-solar perturbation formulations and make other changes and corrections compatible with the orbital program.

4. Develop and implement a more elaborate sun and zenith evasion strategy.

Field Laser Control and Processing Software

1. Restructure the software to accommodate rates to 30 ppm.

2. Accommodate the analog pulse processor; replace digitizer processing routines.

3. Change field routines for both quick-look and final processing to use data from the Analog processor.

Headquarters

1. Modify the Headquarters final data processing to use the data from the analog processor.

7.2.2.1 Field Prediction Software

In order to use the new range gate capability to improve daylight ranging to LAGEOS it is necessary to upgrade the orbit software and field predictions to the sub-microsecond level (100m).

This involves a two step process, the first to verify compatibility between the orbit program and the prediction program and the second to evaluate and refine prediction quality. During the last year extensive examination and numerical testing were performed on the compatibility between the headquarters orbital routines and the field programs. Problem areas that were identified included: 1) a small (10m) discrepancy in the Keplerian motion. 2) a 100-200m per week discrepancy in the lunar theory used in the field prediction packages, 3) a 20m problem in the tesseral

harmonics, and 4) several other small inconsistencies in coordinate systems and timing.

The problems turned out to be a combination of: (1) inconsistencies in models used in the orbital and prediction programs; (2) inconsistencies in the operating procedures of the two programs, and (3) errors in programming and formulation. A more elaborate lunar-solar perturbation was added to the prediction program. Changes were also made to several other routines within the program and operating procedures were more clearly specified. The latest self consistency checks between the orbit and the prediction programs (zeroset) conducted in May and June show internal consistencies in pointing and range to better than 2 arcsec and 10 meters respectively.

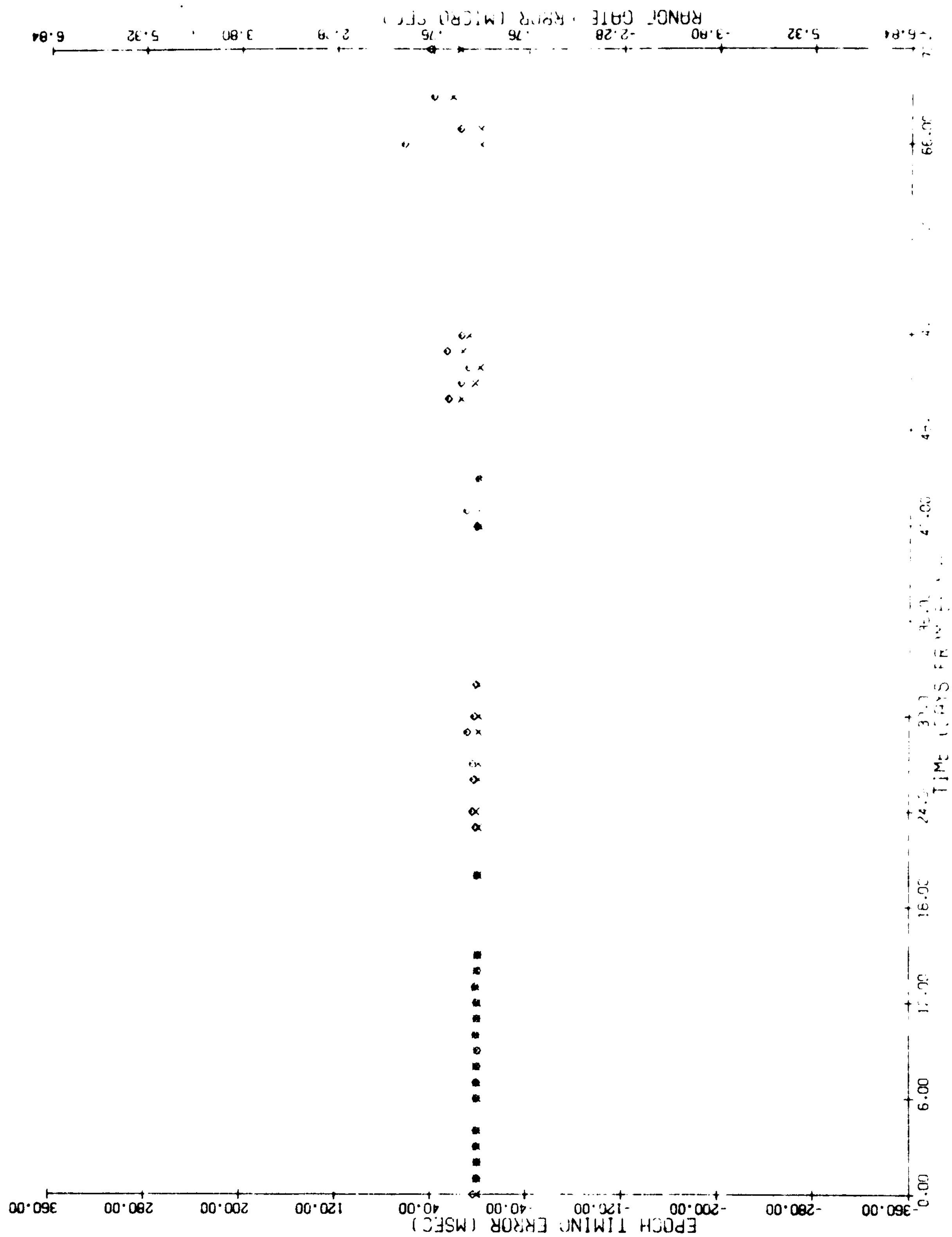
A full test of LAGEOS prediction software and processing system was carried out during the reporting period. The software had been modified to include: 1) more accurate lunar perturbations, 2) solar perturbations, and 3) repair of several small computation errors. In addition, some orbital parameters were introduced analytically (instead of being solved) and the data fitting period was extended to three weeks. The results obtained are shown in Figure 1. LAGEOS predictions when compared with actual data show an accuracy of better than +/-30 meters for a period of 30 days. It appears that more improvement can be derived from a little more care in the calculation of semi-major axis (or period) from historical data if necessary. A more detailed discussion is included in Latimer, et. al., 1981.

During this reporting period satelli dependent rate specifications and zenith and sun evasion strategy for 30 ppm were developed.

A preliminary (prototype) version of the prediction program (FLPPS 6.4) is now in use at Mt. Hopkins to develop some working experience. Work is underway in Cambridge on final clean-up and documentation. In particular, there is still a minor programming bug in the forecast routine and we still have a space problem with the predicted return signal strength routine. Both will be addressed in early 1982.

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 1.



7.2.2.2 Laser Control and Processing Software

In the Laser Control and Processing Software, we have followed a philosophy to ensure us of success at interim stages so that hardware can be tested and hardware can be fielded as soon as possible. The 30 ppm rate imposes some rather tight constraints that might require major changes in software structure and data handling procedures. The software development procedures were thus following two tracks. The first was to modify the current software, removing as many of the waveform related calculations and digitizer data handling procedures, without changing the overall data output structure (both raw and reduced data tape still provided). This would allow us to gain considerable speed and yet not impact the subsequent processing software. It was anticipated that we will reach 14-20 ppm with these modifications which will be available in late FY 1981. In parallel we were also developing a new design for the laser control and processing software that would leave only one output tape and would process considerably faster.

On the basis of our experience now however, it appears that we can come very close, and probably reach 30ppm with modifications of the current software. A version of the software is already working at Mt. Hopkins at 20ppm and several avenues are being pursued in Cambridge to approach the 30ppm rate.

The first approach is to optimize the program code. By converting some of the routines to machine code and improving some of the routine call hierarchies, considerable time can be saved.

The second approach is based on the recognition that every laser shot will not result in a return. However, the software must be able to avoid catastrophe failure if the rate of returns over a short interval is greater than the software capability to process data.

The modifications to gracefully ignore pulses from the laser hardware in the event that the processing falls behind the input has been implemented and is in testing. (These changes will allow lasing at a rate higher than the throughput, in expectation of a lower rate of successful returns and noise stops). In testing the newly modified software, the

Simulator, a program which allows a second Nova minicomputer to simulate the field hardware for testing at headquarters, was found not to transmit the correct framing sequences of control characters around the data lines; this error had not affected the operation of previous versions of Direct Connect, but will cause the system with the latest modifications to fail. The Simulator was changed to correct this problem.

A third approach is to further reduce some of the complex CRT display and further optimize the I/O to reduce data cycle time.

The latest test version of the Laser Control software which already includes some code optimization and the "graceful failure" facility, is also able to accommodate 100 pre and post-pass target calibrations, instead of the previous 25. This code will be tested at Mt. Hopkins in February.

The number of pre and post-calibration lasings permitted was increased by the simple expedient of expanding storage arrays; this was insufficient and work is in progress to achieve a further substantial increase by rewriting the relevant code.

7.2.2.3 Other Software

The target calibration program was modified to obtain the pulse repetition rate from the satellite ranging records in the intermediate data file rather than from zeroset records. Also, the two digits in the intercoupler previously used for indicating operational parameters for the old pulse processing system will now be used to input the repetition rate for the target calibration program.

The target calibration program was also modified to accommodate 30ppm testing at Mt. Hopkins.

8. LASER HARDWARE UPGRADING

Under revision 1 to the FY1981 Proposal (P987-6-80), which was subsequently approved by NASA, SAO embarked upon a program of laser upgrading to bring the SAO lasers to 3-5cm accuracy and to improve data yield for the Crustal Dynamics Program. The key elements of the program were to:

1. Increase the pulse repetition rate from 8 ppm to 24-30 ppm to increase data yield on LAGEOS.

2. Decrease the laser pulse width from 6 nsec to 2 nsec to improve range accuracy.

3. Modify the photoreceiver and the range gate system to reduce range scatter and improve signal-to-noise performance.

A comparison of the key laser system parameters before and after the current upgrading is shown in Table 5 along with estimates of anticipated system accuracy in Table 6.

To accommodate the increased pulse repetition rate and to reduce range noise, we are replacing the waveform digitizer with an analog pulse processor. System Signal to Noise performance, particularly during twilight and daylight ranging, is being improved with a redesign of the photoreceiver to accommodate a 3 Angstrom interference filter and a modification to the range gate generator to reduce the gate window by a factor of 10. Associated with these changes are modifications to hardware, software, and operational procedures.

The modifications are being implemented primarily for LAGEOS. All of the modifications will be applicable to some extent to the lower satellites; however, the higher angular tracking rates and the greater uncertainty in orbital position of the lower satellites will preclude some of the potential for higher data rates and narrow range gate windows.

The program will be completed in early 1982, and should have the lasers prepared well in advance for the next MERIT Campaign.

In this section we report on the status of the engineering construction and deployment. In the next section we discuss the measurement results to date.

Table 5

SAO LASER SYSTEM

PARAMETER	CURRENT	UPGRADED
WAVELENGTH (Å)	6943	6943
ENERGY/PULSE (J)	1.0	0.3
PULSE WIDTH (NSEC)	6	2
REP. RATE (PER MIN)	8	30
DIVERGENCY (MR)	0.6	0.6
QUANTUM EFFICIENCY (%)	4	4
SYSTEM EFFICIENCY (%)	25	25
RECEIVER DIAMETER (M)	.50	.50

Table 6

SAO LASER NETWORK
SYSTEMATIC ERROR SUMMARY

SOURCE	PRESENT SYSTEM	UPGRADED SYSTEM
WAVEFRONT (SPATIAL)	4.5 CM	1.5 CM
SYSTEM DRIFT (TEMPORAL)	6.0 CM	3.0 CM
CALIBRATION (SIGNAL STRENGTH)	6.0 CM	3.0 CM
R.S.S.	9.6 CM	4.5 CM

8.1 Increased Data Rate

The major limitations in pulse repetition rate for the SAO lasers has been the mount and the pulse processing in the computer. In the case of LAGEOS, where the angular rates are very slow, the mount hardware can operate at rates well in excess of 30 ppm so the waveform digitizing and on line processing become the limitation. As part of this upgrading SAO has built an analog pulse processor that provides about the same accuracy (and stability) as the digitizer and yet does not require the on-line processing.

Increasing the laser pulse repetition rate from 8 ppm to 30 ppm requires hardware modifications to (1) the laser power supply, (2) the laser control unit, and (3) the station power systems. In addition, the analog processor must be implemented. All other hardware is presently compatible with the increased rate.

8.2 Power System Modifications

The power system modifications to accommodate the increased data rate were completed at Mt. Hopkins, Orroral Valley and Arequipa in July, November and December respectively.

8.2.1 Laser Power Supply

In early July the manufacturer of the charging transformers informed us of a discharge problem that could inhibit performance. Remedial action caused a months delay, but properly functioning transformers for Mt. Hopkins were delivered in early August.

Factory acceptance testing of the remaining 6 transformers and peripheral parts was completed in September. A pair of transformers were shipped to both Arequipa and Orroral Valley via sea freight while the last set was held in storage awaiting resolution of the Natal station equipment.

The power supply modification was installed and tested at Mt. Hopkins in early October.

By the end of December, the laser had fired over 100K pulses with no difficulties or apparent degradation.

The transformers for the two overseas stations, Arequipa and Orroral Valley, arrived on site in December. The current schedule for the Laser Power Supply is shown in Schedule 1.

8.2.2 Laser Control Unit

Wiring and fabrication of the prototype LCU for Mt. Hopkins was completed in early July. The unit was installed and tested at Mt. Hopkins in October. Minor revisions were made to streamline its operation with the rest of the Laser Ranging System. These revisions have been incorporated into the production units.

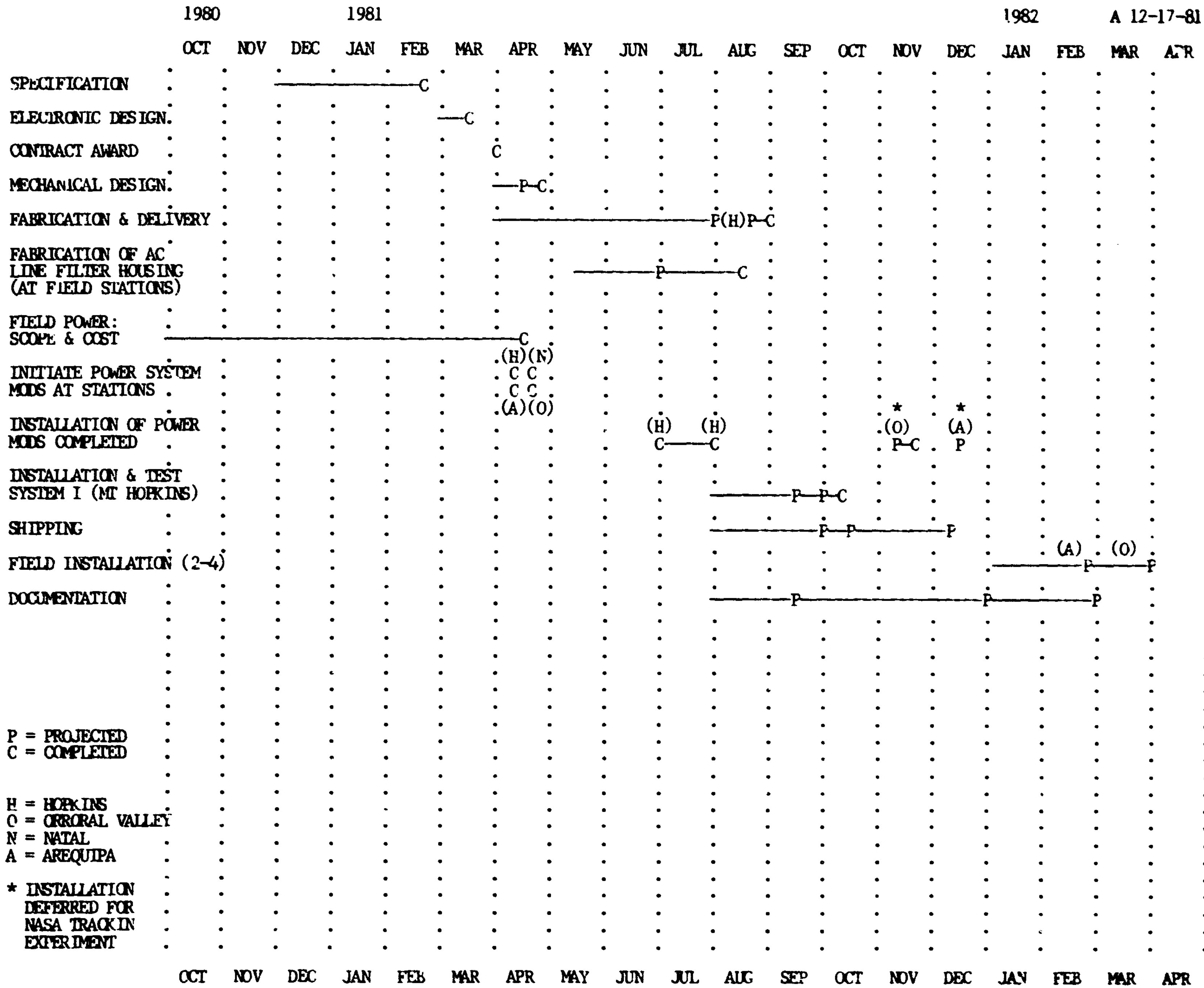
In October work commenced on construction of the production units. Work also began on production of a final documentation package. Final testing was completed in mid-September. All of the initial design goals established for both units were successfully attained.

Construction of two production units was completed in December with testing scheduled for completion in late January. Work is underway on the construction of the final two units although at a more relaxed pace. The current schedule for the Laser Control Unit is shown in Schedule 2.

Development of a microprocessor version of the LCU was also undertaken during this reporting period. A breadboard version demonstrated feasibility in the laboratory and parts have been purchased and delivered to build a prototype.

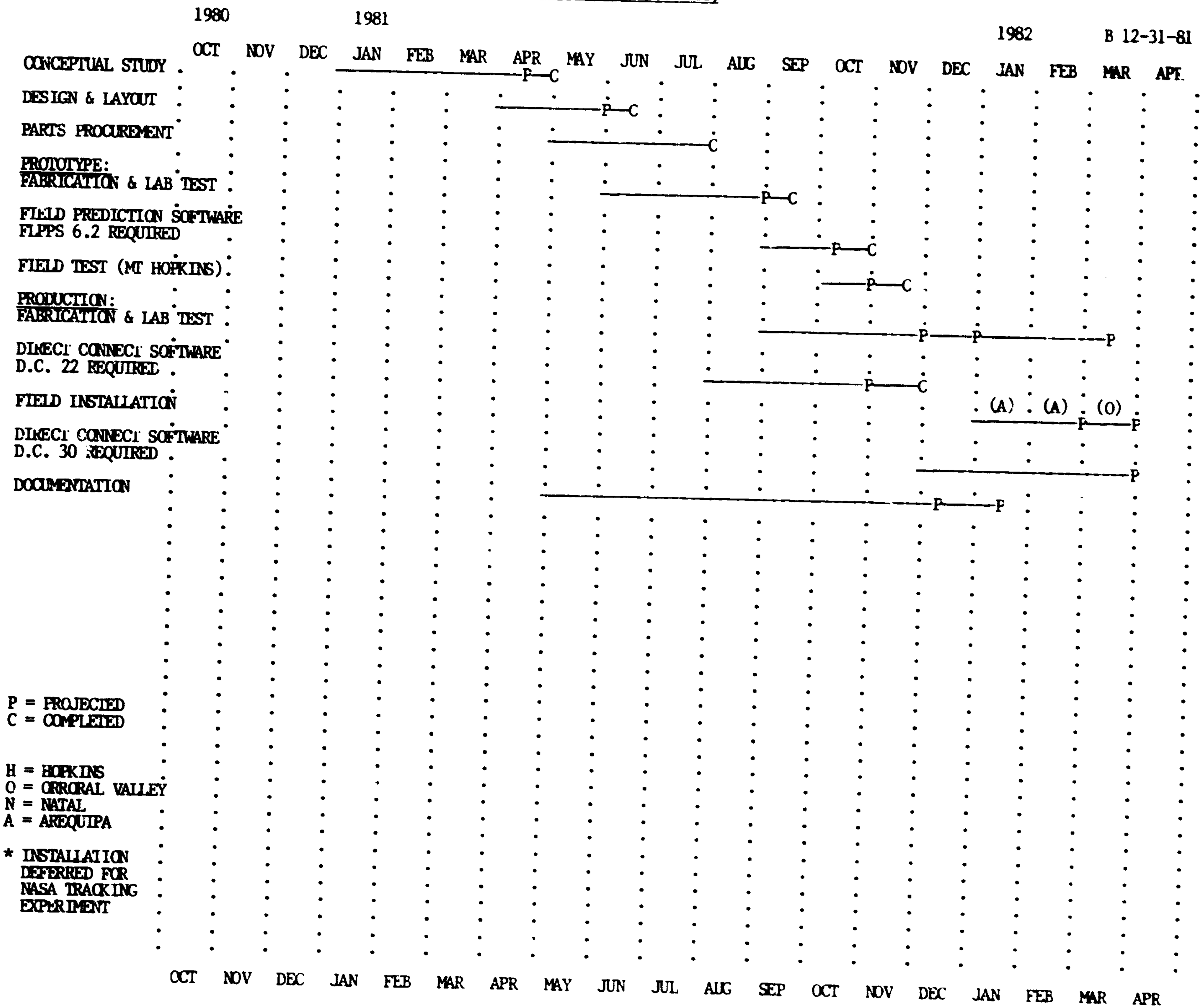
SCHEDULE 1

LASER POWER SUPPLY MODIFICATION (TASK 11)



SCHEDULE 2

LASER CONTROL UNIT (TASK 11)



8.3 Reduction in Laser Pulse Width

The laser pulse width is being reduced to 2-3 nsec by using a shorter ceramic Blumlein structure for the pulse chopper. Fabrication of the Blumlein structures is being done by Lasermetrics, Inc., the builders of SAO's pulse choppers.

In July, the first prototype Blumlein structure was integrated with the chopper electronics from Mt. Hopkins. The event was successfully checked out in the laboratory in August. Installation and testing was carried out at Mt. Hopkins in November. The nominal 2 nsec FWHA Blumlein produced a 2.8 nsec FWHA laser pulse of about 0.4 Joule. The unit worked well through December, however, some pulse misshaping ("back porch") was noted on both the optical and electronic pulse. The production model and spares for the Blumlein were ordered in early December with a promised delivery of the first two units in January. Schedule 3 shows the current progress and plan for the Pulse Chopper modification.

8.4 Improved Range Gate

The SAO lasers currently use a range window of 6-10 microseconds. This poses no difficulty during the nighttime hours; however, at twilight and under daylight conditions the system is very noisy, and operation on LAGEOS is precluded. To improve the system, SAO is modifying the range gate generator to operate at windows down to 0.1 microseconds. Design of this modification is now complete and fabrication is underway (see Schedule 4).

Lab testing of the Range Gate Modification using prototype boards was completed in July. The test showed that a 100 nanosecond window could be achieved with a jitter of +/-50 nanoseconds. Additional reduction in jitter was expected with the PC versions of the prototype boards. Artwork of the production version of the PC cards was also completed and checked out in July.

The PC cards for the production version was delivered in mid-August. One set of the cards was constructed and tested, showing a reduced jitter of +/-2 nanoseconds.

In September, installation and testing procedures were written, and a field modification package was prepared at Mt. Hopkins. Documentation, (new and revised drawings, wire-lists etc.) was also completed.

Four additional sets of production boards were built in September and tested in October.

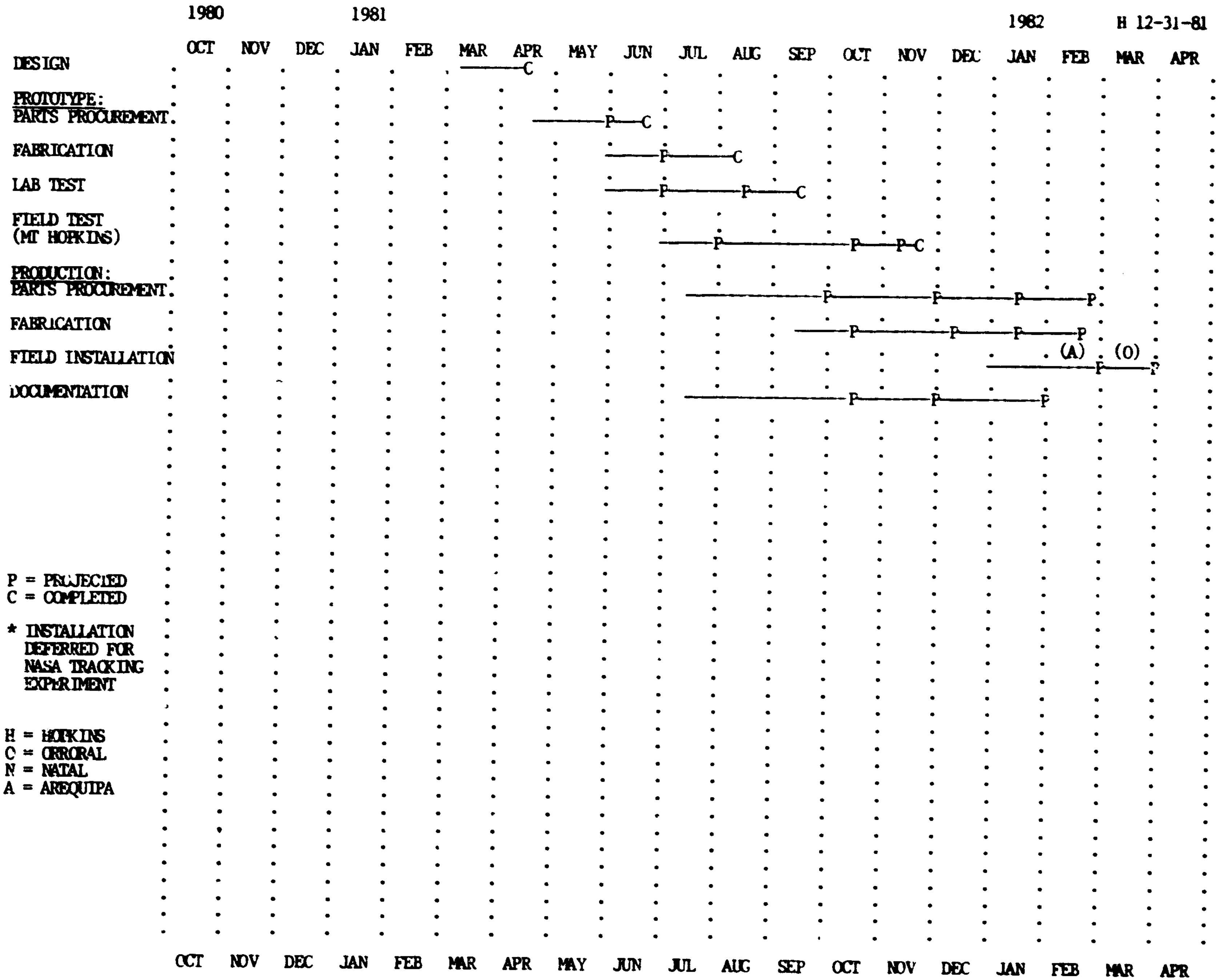
The range gate modification was installed at Mt. Hopkins in October. The modification, which entailed revisions to three of the existing data system chassis, was successfully tested in manual mode with a maximum jitter of +/-2 nsec.

With the availability of proper software in December, the prototype range gate at Mt. Hopkins was successfully tested in auto-mode; no apparent problems have been encountered.

The in chassis burn-in tests of the production board sets (4-sets) were completed for two board sets in December; the remaining two sets will be finished in January. The tests pinpointed a potential stability problem on one of the boards due to device (I.C.) compatibility. The problem was resolved by selecting a higher speed logic family for the circuit in question. The new logic is pin-for-pin compatible with the original devices thus no board redesign was necessary. The current status and schedule for the range gate modification appears in Schedule 4.

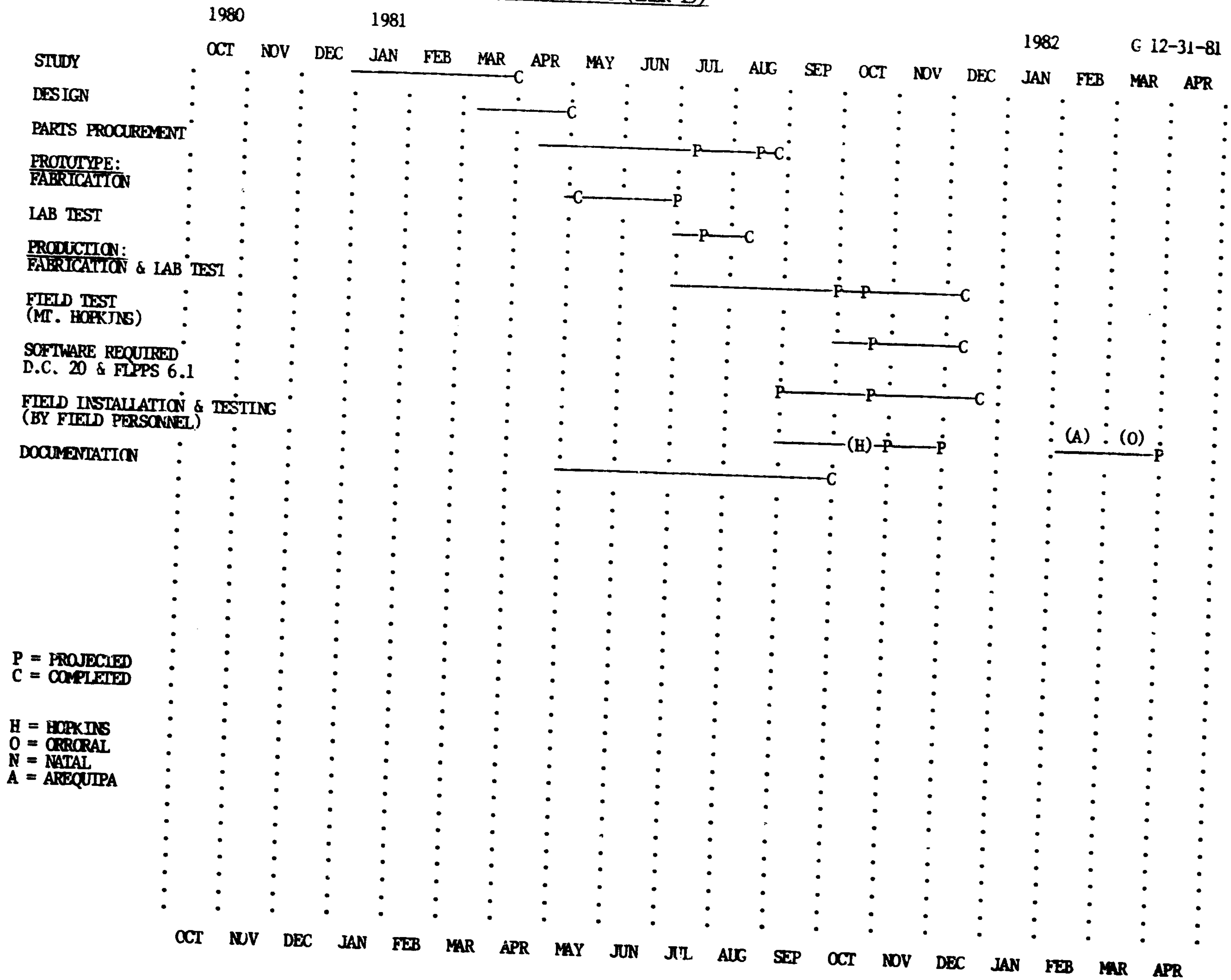
SCHEDULE 3

PULSE CHOPPER (TASK 16)



SCHEDULE 4

RANGE GATE MODIFICATIONS (TASK 15)



8.5 Modifications to the Photoreceiver

In July, most of the optics for the prototype system for Mt. Hopkins were assembled and tested without problems, and the PMT shutter control boxes were finished and tested.

The first two narrow band filters were delivered with transmission of 55% and 47% at passbands of 3.2 and 3.0 Angstrom respectively. The production model PMT bases and housings were also delivered in July. The last outstanding lenses for the prototype system were delivered in September. Some of the PMT bases were found to have wrong spacers installed and were returned to the vendor for correction. These were returned in October and tested with the pico second laser pulser.

Initial installation of the photoreceiver package in October at Mt. Hopkins showed that additional adjustments for lateral centering were needed in the mechanical assemblies. Some pieces were reworked locally while others were returned to Cambridge for rework. The complete package was finally installed and aligned at Mt. Hopkins by the end of the month.

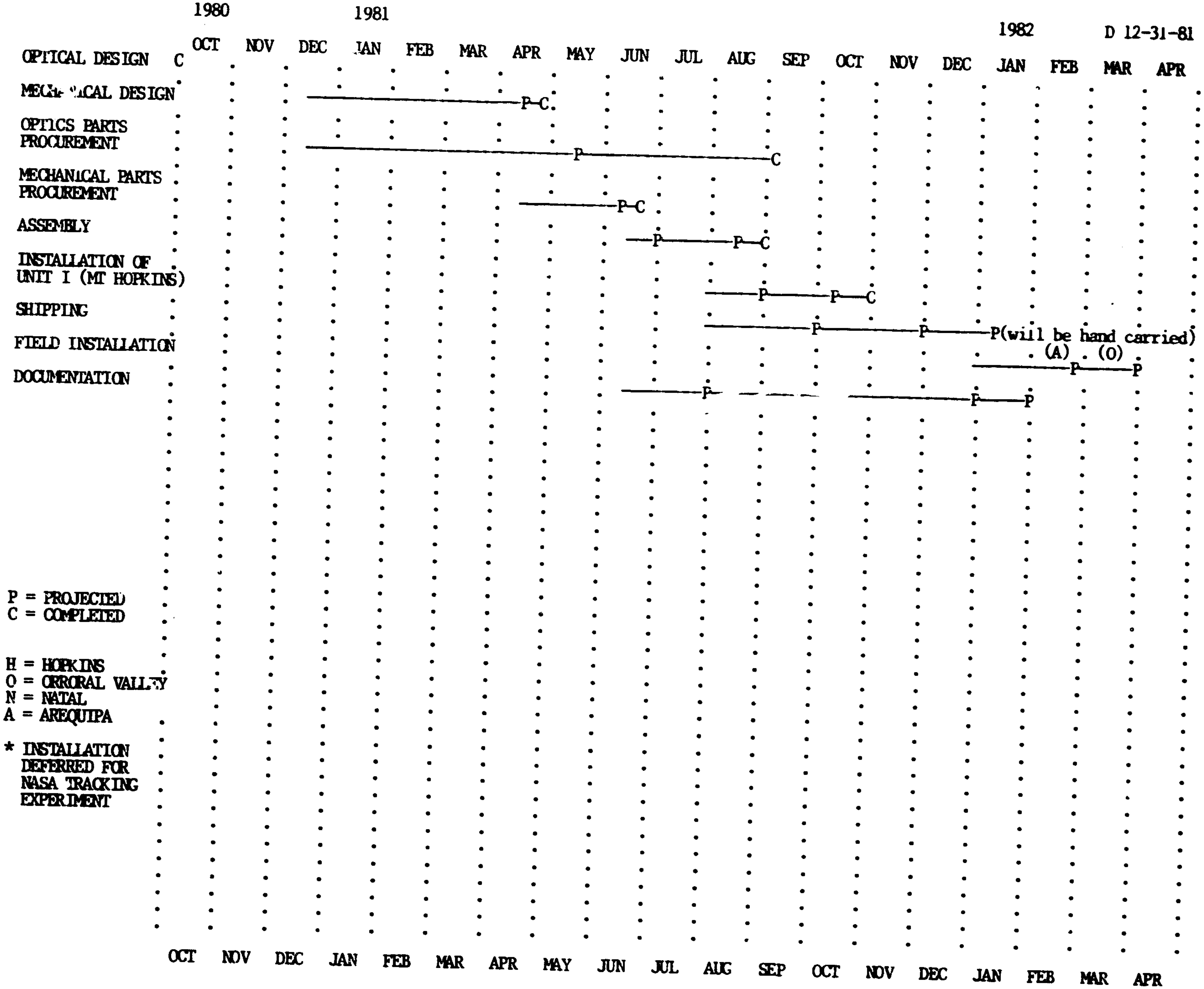
The PMT assembly was installed at Mt.Hopkins in October and tested in November. The output pulse showed a rise time of 2.5 nsec and a FWHA of 4 nsec at the single photoelectron level.

Although tuning and calibration of the 0.3 nanometer interference filter will be done until early 1982 at Mt. Hopkins, the experience to date using the manufacturers' calibration data to set the filter oven temperature, indicates good transmission characteristics.

Successful satellite ranging at Mt. Hopkins in late December has confirmed the need for the lateral centering adjustments on the new lens holders. The mechanical reworking of the lens holder (for sites 2, 3 and 4) is still scheduled for completion in January.

An additional aperture stop will be added to the front of the PMT assembly at Mt. Hopkins in an attempt to limit the effective aperture of the PMT. This should reduce the transit time jitter of the PMT. This test will be tried at Mt. Hopkins in late January to early February. The schedule for the photoreceiver is shown in Schedule 5.

SCHEDULE 5
PHOTO RECEIVER (TASK 14)



8.6 Analog Pulse Detector

A fundamental element to the increased data rate and the improved accuracy is the analog pulse detector. Not only does this reduce considerably the data processing per pulse over the digitizer and thereby make the 30ppm mode possible, but for very narrow pulses it also avoids errors introduced through inadequate pulse amplitude sampling. In addition, it also avoids the inherent complexities of the WD2000 and the related pulse processing software.

Several different analog pulse processor configurations were tested at Mt. Hopkins in the previous reporting period for range noise, stability, and flatness of response over the dynamic operating range. The best results were found with a matched filter, a differentiator, and a low threshold discriminator used as a cross-over detector.

A schedule for construction and fielding of the analog pulse processor is shown in Schedule 6.

In July, the final outstanding parts were received and fabrication of the Processors was completed. Tests of the units for operation at 6 nanoseconds were made and further testing will be made in August to prove operation of the detector at 2-3 nanosecond pulse widths.

Preliminary tests for 2-3 nanosecond operation indicate that only a reduction in delay line lengths of the Matched Filter will be required for the shorter pulse operation.

Modifications to allow individual gating of the LeCroy 821 Discriminators were delayed. It was found that changes in circuit design and board layout had been made by the manufacturer between the unit used in prototype testing and those purchased for the production Analog Detector. Board layout information has been requested and will be sent by the manufacturer. The modification are scheduled to be completed in late August. All of the Ortec 934 Constant Fraction Discriminators have now been modified for individual gating.

Initial lab testing of the analog processor for operation at 2-3 nanoseconds was completed in September. Redesign of the LeCroy 821 Discriminators for individual gating was completed, and one unit was successfully modified and tested in preparation for Mt. Hopkins.

In conjunction with the gate circuit revisions and testing, calibration techniques were developed for both of these new LeCroy and Ortec modules.

In October the three remaining LeCroy 821 discriminators were modified for individual gating. Final testing of the individual gating modification for the LeCroy 821 discriminator was completed in November.

The analog processor was installed at Mt. Hopkins in October. Field trials over a two month period have prompted some configuration revisions. These changes pertain mainly to variations in module connecting schemes which are now being incorporated into the remaining units.

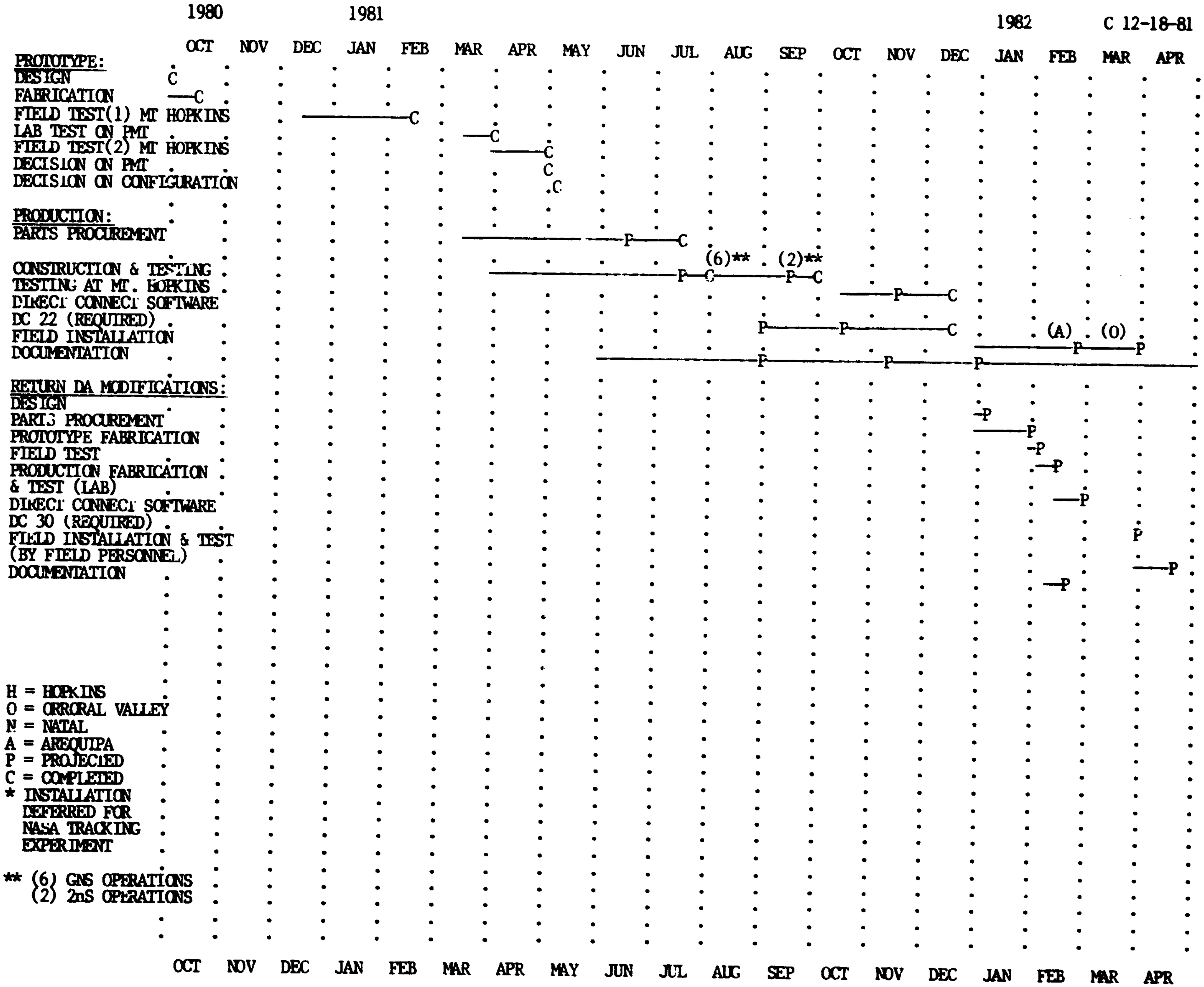
8.7 Transmitter Detector

One of the major sources of range jitter in the SAO lasers is the start pulse diode in the transmitter, which under the upgrading program is being replaced. Several diodes were tested along with commercially available and SAO built bases. The best results were derived from a Hammamatsu P. I. N. diode and base. These will be installed in the fall (see Schedule 7).

Construction and assembly of the detectors was completed in late August. In September, the production detector assemblies were tested in the laboratory. The detectors were successfully field tested at Mt. Hopkins in November providing 6 volts output as required. We may want to add a bit more amplification in the future for long term stability.

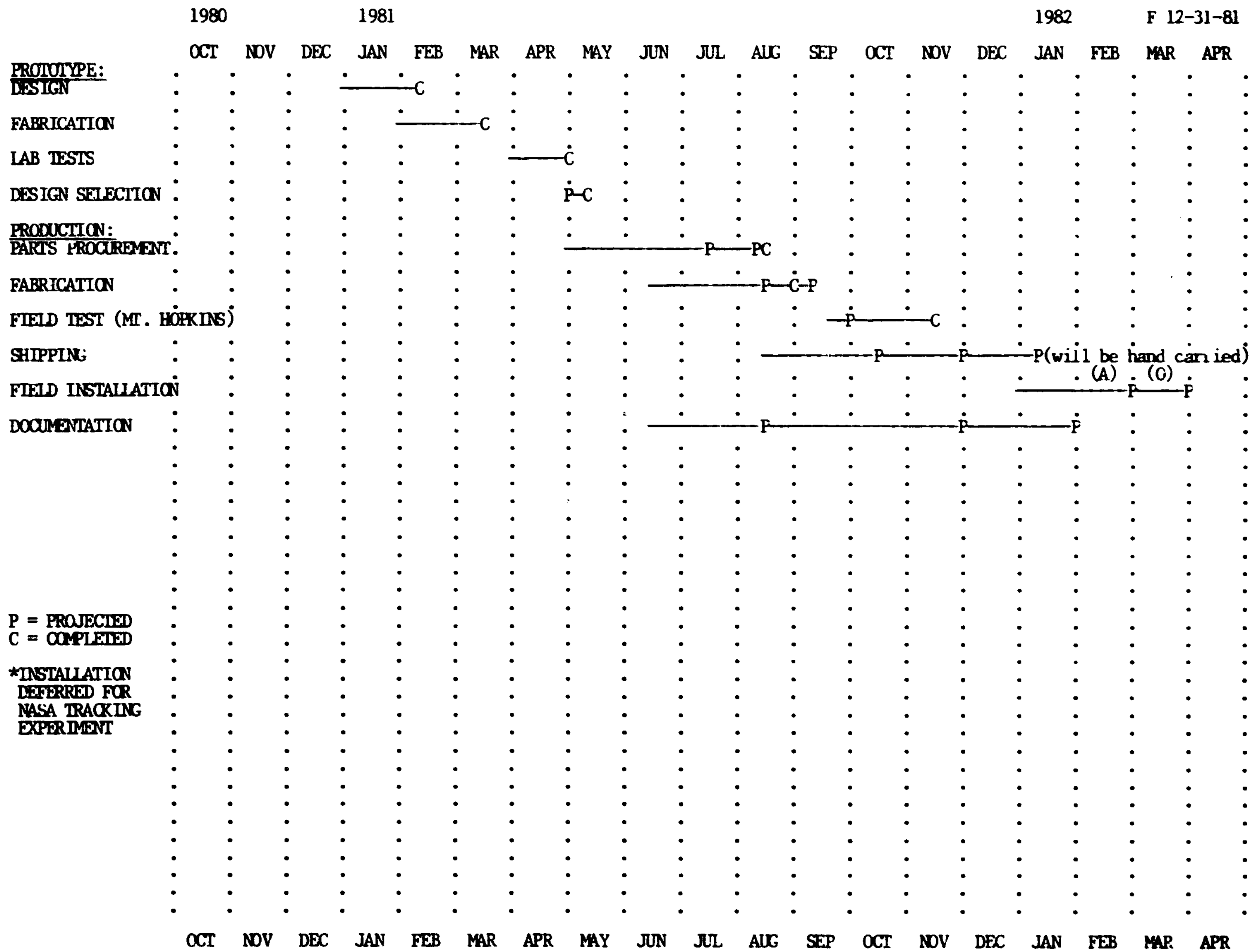
SCHEDULE 6

ANALOG PROCESSOR (TASK 12)



SCHEDULE 7

TRANSMITTER DETECTOR (TASK 13)



9. DATA QUALITY

Since the installation of the pulse chopper, coupled with improved pulse processing, the SAO laser systems have been operating at an estimated 10 cm accuracy. This higher accuracy, however, must be monitored very carefully to ensure that the system does not degrade and that the ranging capability is maintained.

9.1 Systematic errors

The systematic errors of the laser ranging system can be divided into three categories: spatial, temporal, and intensity (signal-strength) variations. Spatial variations refer to differences in time of flight depending on the position of the target within the laser beam. Temporal variations relate to system drift between prepass calibrations, satellite ranging, and postpass calibration. Range variations due to changes in signal strength are a function of receiver characteristics and digitizer sampling interval.

Spatial variations, or the wavefront error, have been measured at Mt. Hopkins several times using a retroreflector. The results have been discussed in previous reports. The temporal variations are estimated by the difference between prepass and postpass calibrations measurements. Examples of these measurements taken during FY 1981 are shown in figures 2, 3 and 4. These differences represent an upper bound, since other statistical errors are also included.

Variations in apparent range with signal strength have been examined with extended target calibrations over the dynamic range of the laser instrument. Examples of these are shown in figures 5 and 6.

Using typical mean error values of 4.5, 6, and 6 cm for the spatial, temporal, and signal-strength variations, and assuming that these errors are independent, the root-sum square (rss) error due to systematic sources is about 9.6 cm (see Table 7).

Table 7. Summary of systematic errors

Source	High Satellites (cm)
Wavefront distortion (spatial)	4.5
System drift (temporal)	6.0
Calibration (signal strength)	6.0
rss	9.6

Figure 2

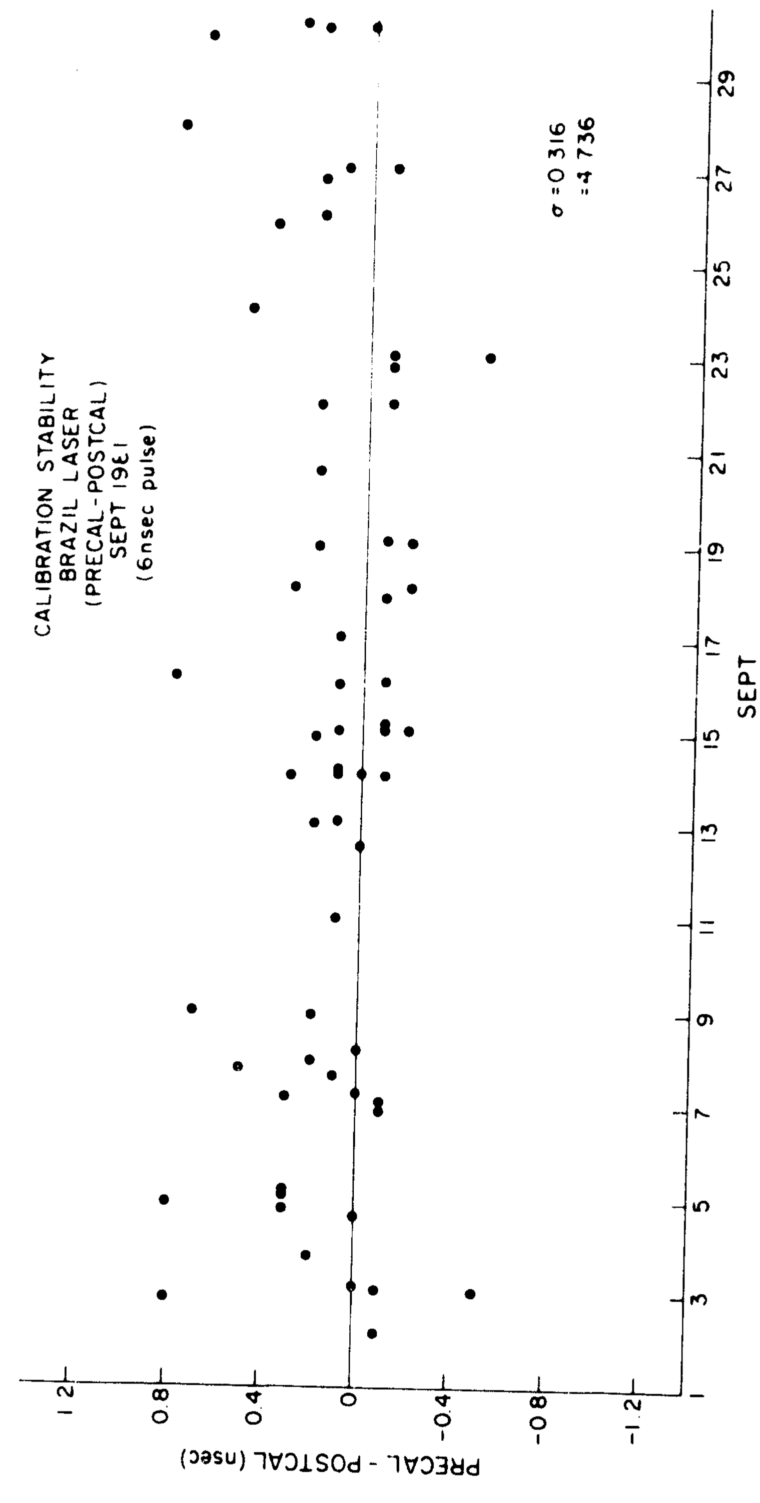

CALIBRATION STABILITY
BRAZIL LASER
(PRECAL-POSTCAL)
SEPT 1981
(6nsec pulse)
σ =0 316
=4 736
PRECAL - POSTCAL (nsec)
SEPT
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
3
5
7
9
11
13
15
17
19
21
23
25
27
29

Figure 3

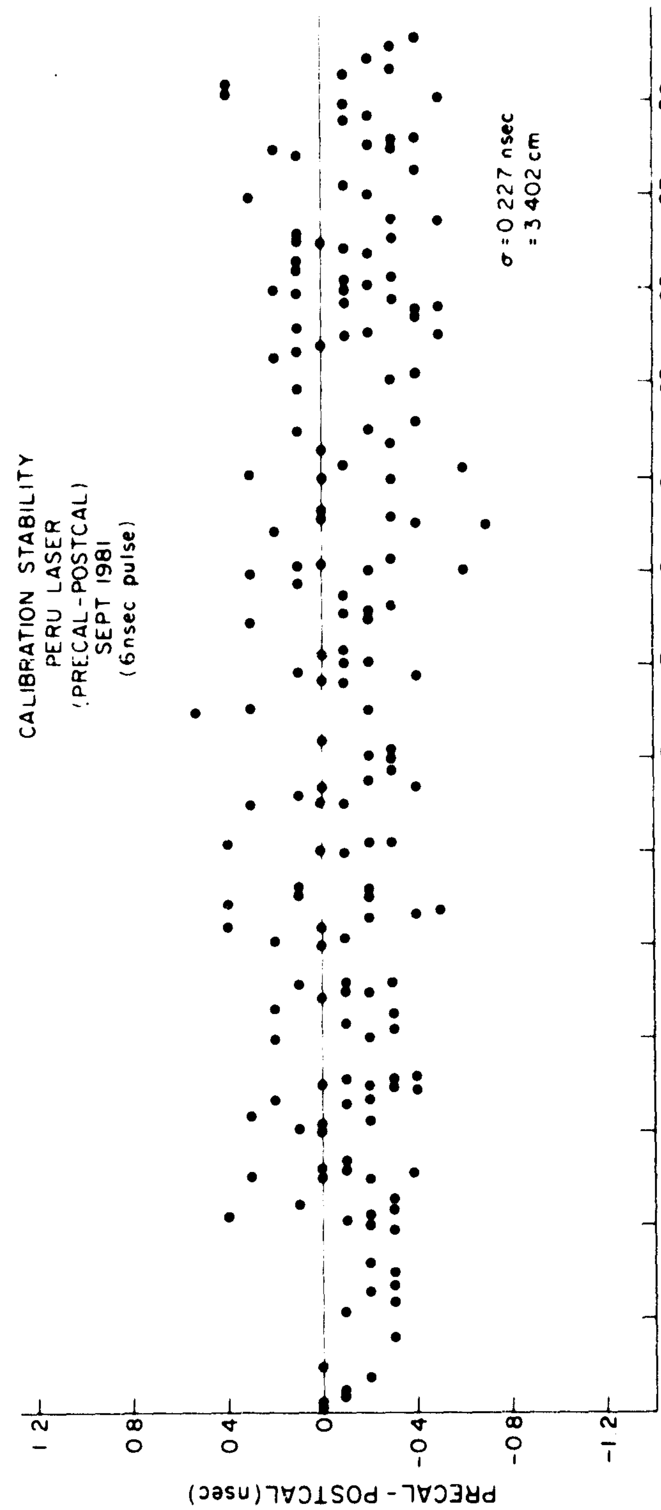

CALIBRATION STABILITY
PERU LASER
(PRECAL-POSTCAL)
SEPT 1981
(6nsec pulse)
σ = 0.227 nsec
= 3.402 cm
SEPT
PRECAL - POSTCAL (nsec)
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
3
5
7
9
11
13
15
17
19
21
23
25
27
29

Figure 4

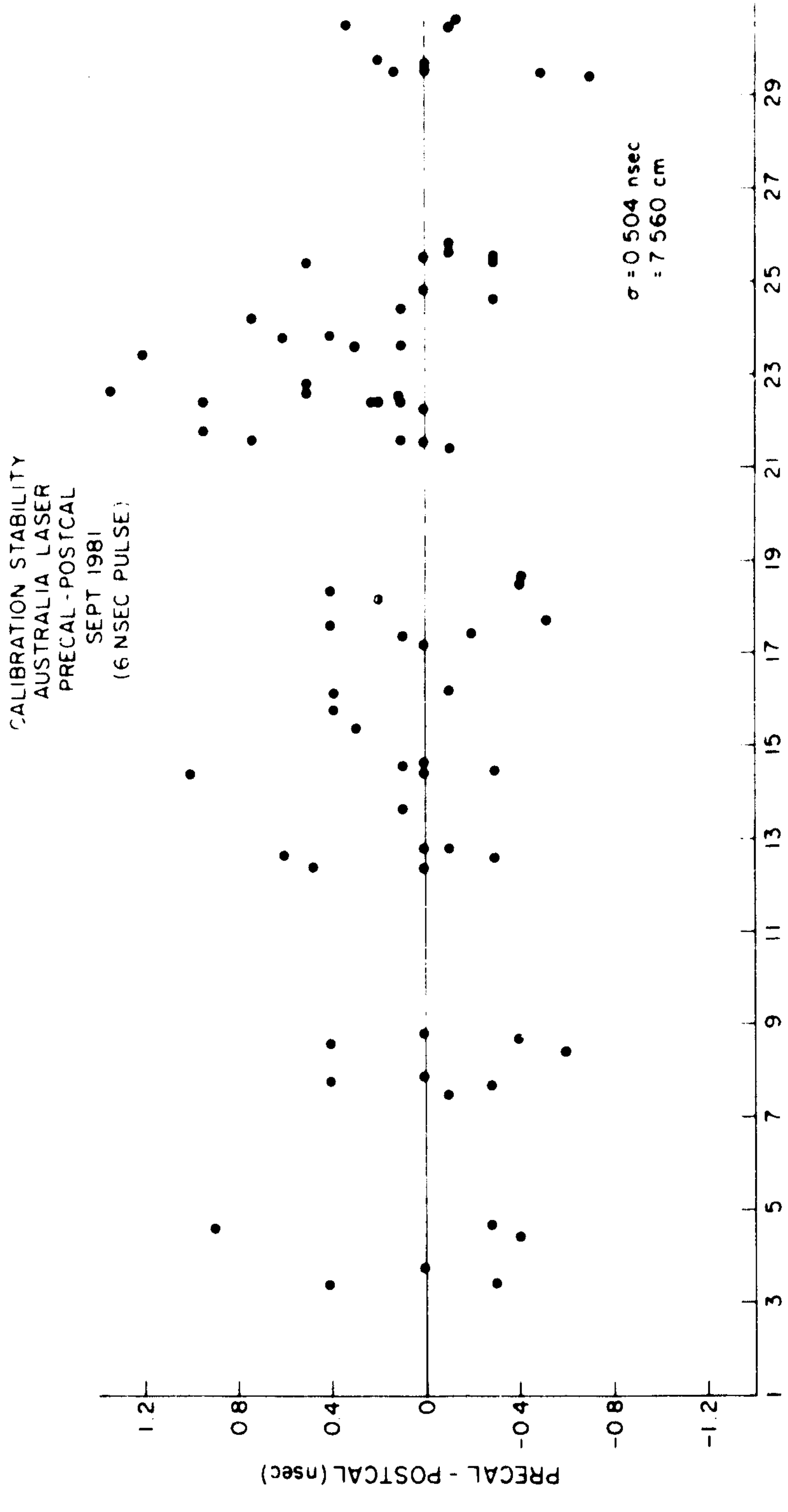

CALIBRATION STABILITY
AUSTRALIA LASER
PRECAL - POSTCAL
SEPT 1981
(6 NSEC PULSE)
σ = 0.504 nsec
= 7.560 cm
PRECAL - POSTCAL (nsec)
SEPT
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29

Figure 5

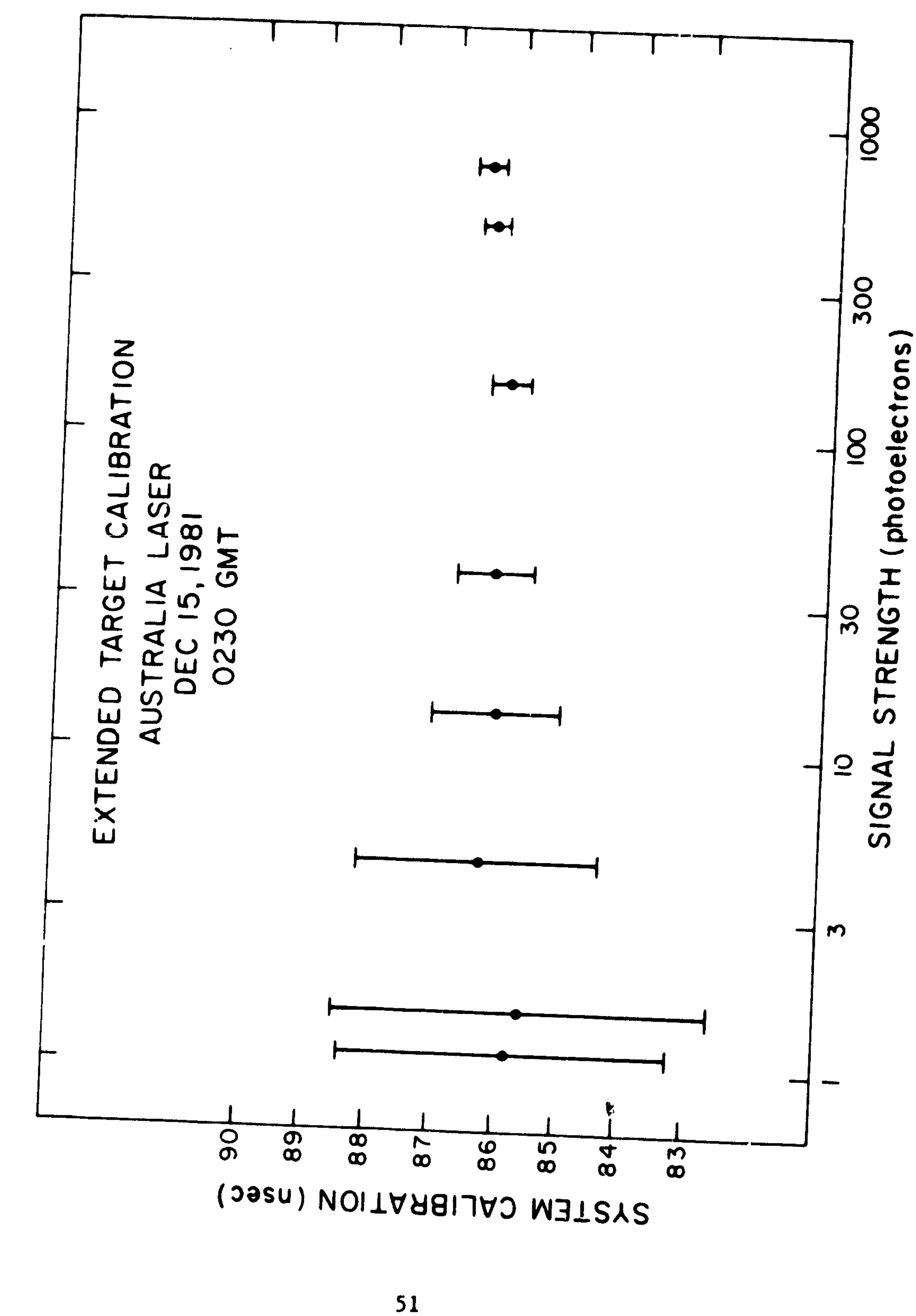
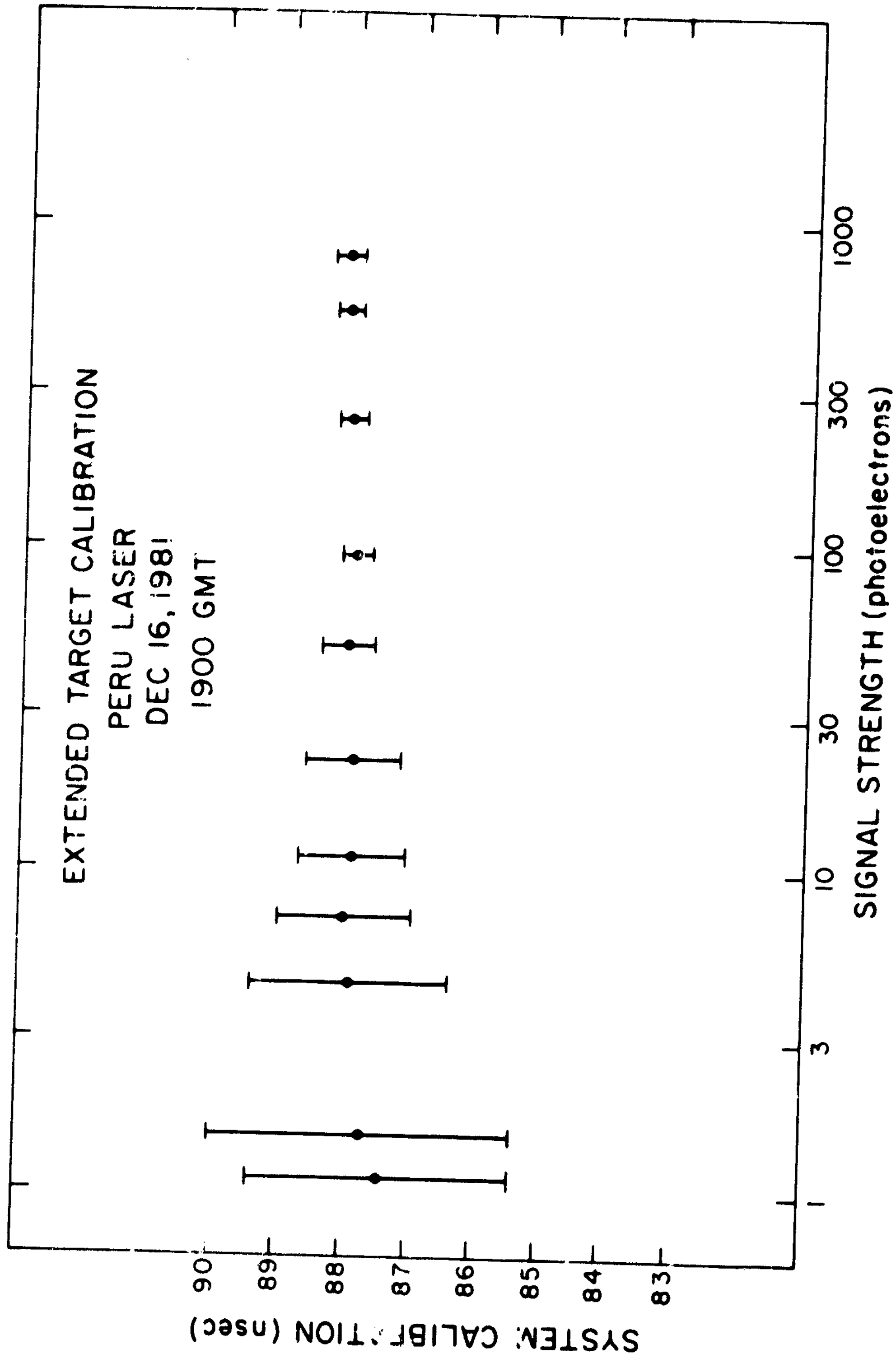

EXTENDED TARGET CALIBRATION
AUSTRALIA LASER
DEC 15, 1981
0230 GMT
SIGNAL STRENGTH (photoelectrons)
1
3
10
30
100
300
1000
SYSTEM CALIBRATION (nsec)
90
89
88
87
86
85
84
83

Figure 6


EXTENDED TARGET CALIBRATION
PERU LASER
DEC 16, 1981
1900 GMT
SIGNAL STRENGTH (photoelectrons)
1
3
10
30
100
300
1000
SYSTEM CALIBRATION (nsec)
90
89
88
87
86
85
84
83

These then, are the systematic errors that can be expected for data averaged over a pass. In addition, errors in timing, refraction, and spacecraft center-of-mass corrections need to be applied to the data; these errors are typically the same as those in the NASA systems, since essentially the same equipment and models are used.

9.2 System Noise

The range noise in the SAO lasers is determined in large part by return signal strength. Table 8 shows 1981 passes taken at Australia and Arequipa on LAGEOS.

With LAGEOS, at signal strengths of a few photoelectrons, noise figures 20-50 cm. It should be noted that the Poisson statistics for photon-quantization with a single photoelectron return from a 6-nsec chopped pulse is about 30 to 40 cm. Some additional noise is added through inadequate sampling of single photon events using the WD2000 with a 1 nsec spacing. Much of the effect of this scatter from photon quantization and jitter is averaged out over the course of a pass.

LAGEOS

PRECAL - POSTCAL
FINAL DATA
OCTOBER 20 - 31
(1980)

Station	Date	Pass Stability (Pre-Post Calibration) (CM)	RMS (Residual to Polynomial fit) (CM)	Number of Points
Peru	10/20	1.05	31.8	68
Australia	10/22	3.45	28.5	111
Australia	10/22	-5.40	31.5	137
Brazil	10/24	-2.70	45.6	33
Australia	10/25	-0.30	56.4	37
Australia	10/25	9.60	50.0	97
Australia	10/26	-5.55	23.0	12
Australia	10/26	-0.75	39.7	96
Australia	10/26	4.05	65.5	14
Australia	10/28	7.05	52.9	63
Australia	10/28	7.35	38.9	144
Australia	10/29	-7.65	28.4	33
Australia	10/29	6.75	36.5	106
Australia	10/29	-3.00	33.8	125
Brazil	10/29	-4.95	37.3	39
Australia	10/30	7.05	30.2	36
Peru	10/30	-2.40	30.1	46
Peru	10/31	0.00	51.5	78

10. CURRENT EVALUATION OF UPGRADED DATA QUALITY

The first field tests of the laser upgrading (see Section 7) were conducted in December. Although performance does not yet satisfy all expectations, considerable improvement can already be seen, and specific technical areas are now being addressed.

In the following subsections, several key factors and test results associated with the determination of data quality are reviewed along with the current status of technical quality.

10.1 Systematic errors

The systematic errors of upgraded laser ranging system have been measured with ground targets. Once again, we have separated these errors into three categories: spatial, temporal, and signal-strength variations. Refer to section 9.1 for a definition of these individual components.

10.1.1 Spatial variations.

Spatial variations, or the wavefront error, were measured at Mt. Hopkins in December. Table 9 gives the history of results before and after the upgrading. The runs taken on 11 December and 14 show no improvement over the 6 nsec pulse. Both of these runs were complicated by operational start up difficulties. The rms values on 15 December were marginally better giving an rms distortion of less than .15 nsec (~2cm). There was a more substantial improvement in the peak-to-peak value.

With the reduction in pulse width from 6 nsec to 3 nsec we would have anticipated a reduction in the rms wavefront to about 0.1 nsec. This indicates to us that the pulse chopper is not yet operating in an optimum fashion (see Section 10.3).

Table 9.

WAVEFRONT MEASUREMENTS

MT. HOPKINS LASER

Laser Pulse Width (nsec)	Date of measurement	Spacing between points (arcmin)	Average number of photoelectrons received	RMS wavefront distortion (nsec)	Maximum excursion (nsec)
20	26 Feb 1974	0.3	88	1.4	3.9
20	18 Mar 1974	0.6	56	0.8	2.7
6	09 Nov 1978	0.3	56	0.19	0.6
6	01 Dec 1978	0.42	87	0.17	0.6
3	11 Dec 1981	0.42	12	0.17	0.51
3	14 Dec 1981	0.42	12	0.19	0.77
3	15 Dec 1981	0.42	13	0.14	0.44
3	15 Dec 1981	0.42	13	0.13	0.45

10.1.2 Temporal variations.

The temporal variations are estimated by the difference between prepass and postpass calibration measurements. These differences represent an upper bound, since other statistical errors are also included. Only a small number of satellite passes were taken at Mt. Hopkins during December. Aside from the first few passes in which we had the usual start-up problems, the bulk of the data had differences of less than .25 nsec (3.5 cm). (Data taken subsequently in January is of comparable quality). Our original expectation for short term stability for the upgraded system was .2nsec (3 cm). (See Figure 7). From our very limited data to date (plus that taken in January) it appears that we are close to our expectation.

Long term system drift tests were also conducted at Mt. Hopkins in December. These tests indicated that long term system drift over several hours may be as large as .3-.4 nsec. However, these tests were conducted over a wide range of operating conditions (output power, operating temperature, repetition rate, etc.) so it really represents an extreme upper bound.

10.1.3 Signal-strength variations.

Variations in apparent range with signal strength have been examined with extended target calibrations over the new dynamic range of the laser instrument. Returns are typically in the range of 1-30 photoelectrons (p.e.). Returns from LAGEOS are at the single photoelectron level. Figure 8 shows tests taken at Mt. Hopkins in December. The mean calibration over the range of 1-50 photoelectrons is flat to better than .2 nsec (3 cm). We had anticipated a result of .2 nsec so it appears that we will meet our expectation.

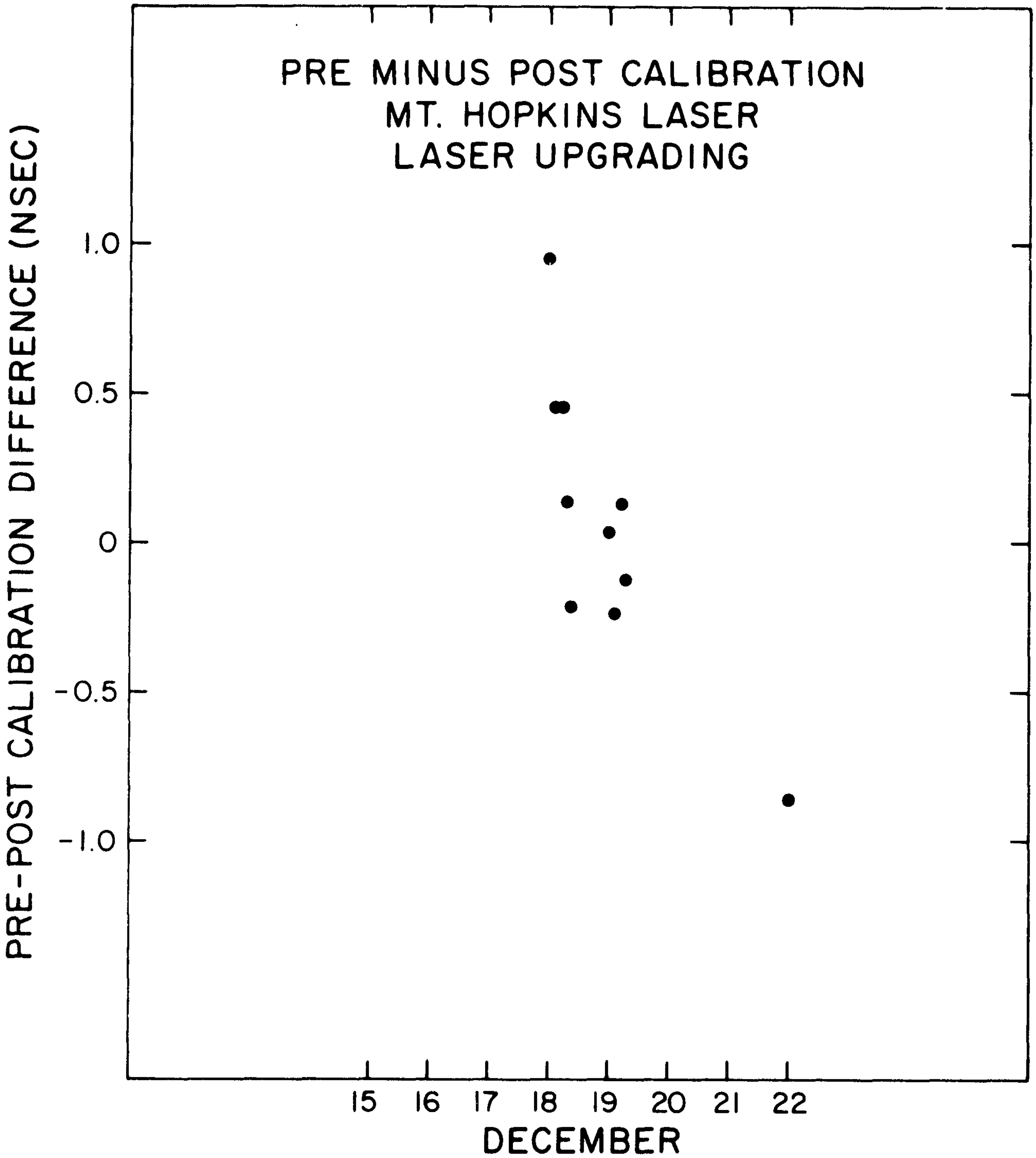
Figure 7.

Satellite Data

Mt. Hopkins Tests

Date	Satellite	Time	Pass Stability (nsec)	RMS (cm)	Number of Points
12/18/81	6503201	01H02M	-0.95	117	25
12/18/81	6508901	01H46M	0.44	134	31
12/18/81	7603901	02H06M	0.44	47	52
12/18/81	6503201	02H58M	0.44	12	49
12/18/81	7502701	03H58M	0.14	64	52
12/18/81	6503201	04H52M	-0.21	12	61
12/19/81	6503201	00H02M	0.04	390	9
12/19/81	7603901	00H44M	-0.23	Rejected	
12/19/81	6508901	01H52M	0.13	17	42
12/19/81	6503201	02H14M	-0.13	Rejected	
12/22/81	7603901	00H26M	-0.86	Rejected	

Figure 8.

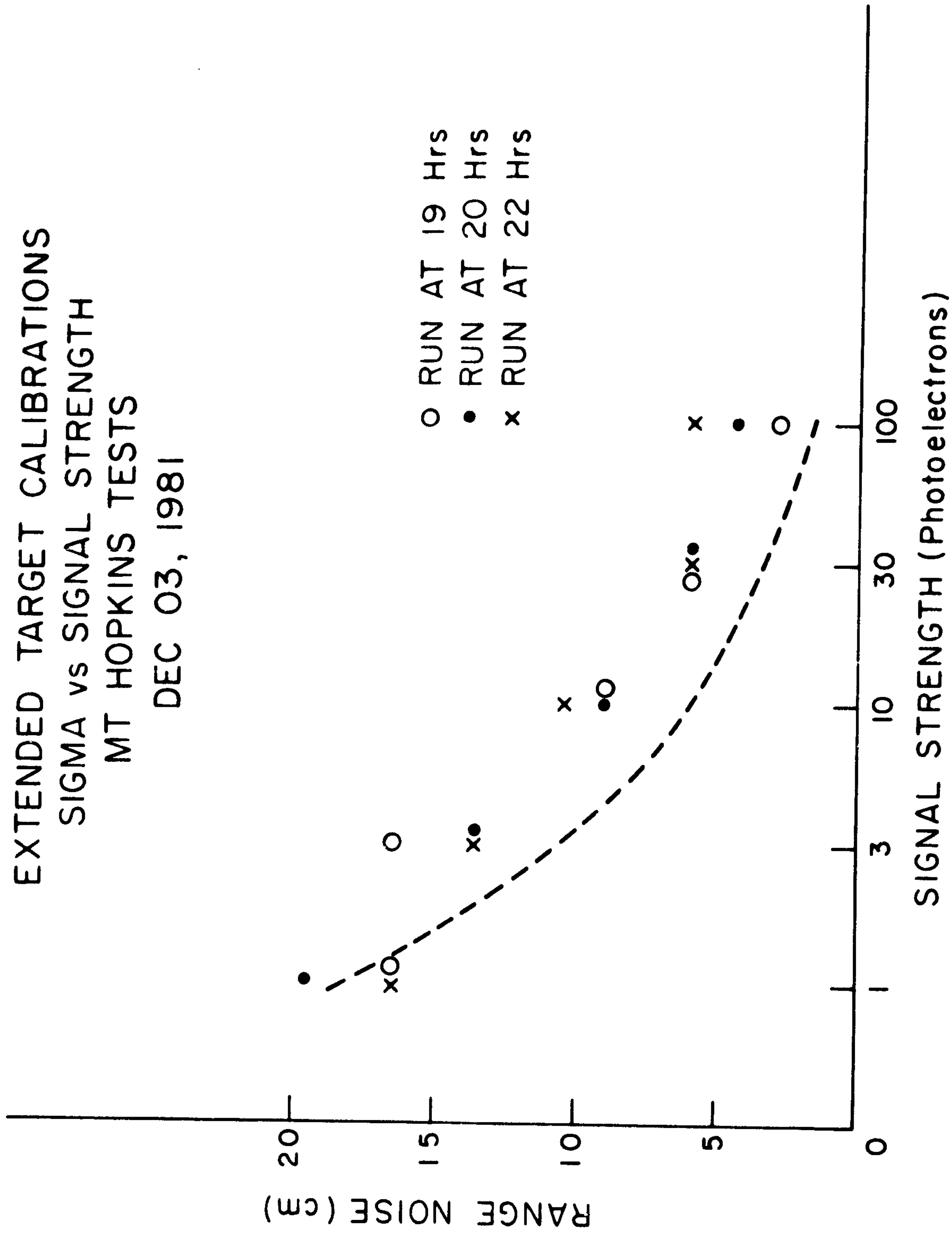

PRE MINUS POST CALIBRATION
MT. HOPKINS LASER
LASER UPGRADING
PRE-POST CALIBRATION DIFFERENCE (NSEC)
1.0
0.5
0
-0.5
-1.0
15
16
17
18
19
20
21
22
DECEMBER

10.2 System Noise

The first estimates of system noise performance were determined from ground target calibration. Figure 9 shows the results of an extended target calibration with the theoretical response for a 3 nsec gaussian pulse. The system appears to give rms values quite close to the theoretical limit at the single photon level (16-18 cm). The noise seems to be about twice the theoretical value in the 30-100 photo region. This indicates that the inherent system (electronic) noise is about .2-.4 nsec. This is a factor of 2-3 higher than anticipated and is under examination at the moment.

As of the end of December, only a small number of satellite passes had been tracked, with only one of them being LAGEOS (see Figure 7). In general, on this very limited set of data, the range noise was 10-50 cm, or in some cases about a factor of two larger than expected. In particular, the results on the one LAGEOS pass indicated that there was some problem with the pulse chopper (see section 10.3).

Figure 9.


EXTENDED TARGET CALIBRATIONS
SIGMA vs SIGNAL STRENGTH
MT HOPKINS TESTS
DEC 03, 1981
o RUN AT 19 Hrs
• RUN AT 20 Hrs
x RUN AT 22 Hrs
RANGE NOISE (cm)
0
5
10
15
20
SIGNAL STRENGTH (Photoelectrons)
1
3
10
30
100

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10.3 Evaluation and Current Action

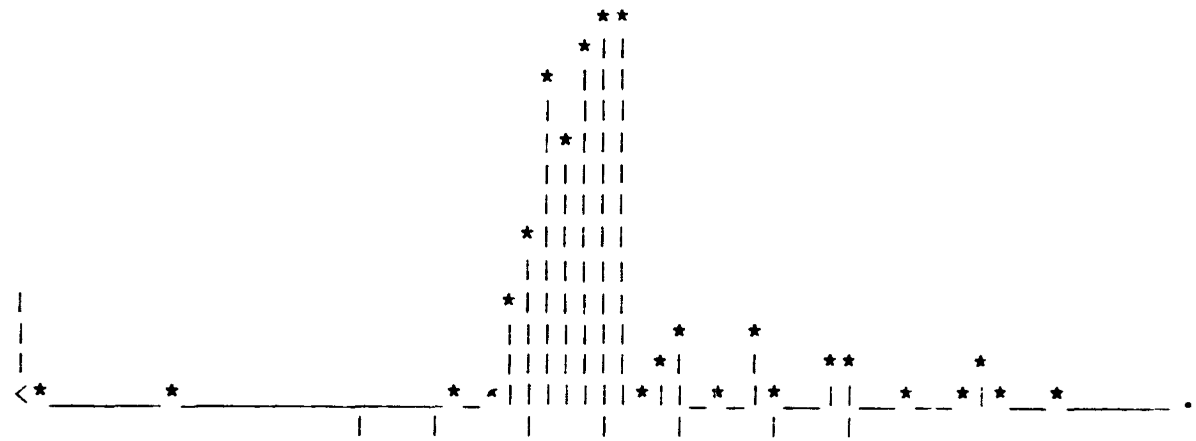
A summary of the test results to date is shown in Figure 10. The system noise level on LAGEOS and the larger-than-anticipated variation in wavefront have motivated us to look more closely at the pulse chopper. A close examination of the laser residuals on LAGEOS (See Figure 11) shows a distinct "back porch" or tail on the distribution. An examination of the pulse chopper laser pulse (See Figure 12) and the electronic drive pulse shows this same structure. Action is underway now to remove the after pulse by better matching the high voltage terminal in the pulse chopper electronics to the Blumlein structure. Initial lab tests indicate that considerable improvement can be attained by reducing the length and removing a bend in the stripline connector. In addition, we are also building an additional Blumlein board which should reduce the pulse width further (from the current 3 nsec).

Aside from the activity underway with the pulse chopper, we are now conducting an end-to-end electronic test of the detection system to characterize the noise response and systematic effects, and to look for any performance anomalies. Special attention is being paid to the matched filter which currently has a gaussian shaped response. it appears that we would do better by matching the filter to the single photon response of the PMT.

Figure 10.

Summary of Tests

	To Date	Goal
Wavefront Distortion		
RMS	.15ns	.1ns
Peak-to-Peak	.5ns	
System Stability		
Pre/Post Cal	.2ns	.2ns
Long Term	.3ns	
Variation in System Delay (1 - 30 Pe)	.25ns	.2ns
System Noise (Target Calibration)		
At 1 Pe	1.1ns	1.1ns
At 30 Pe	.5ns	.25ns
System Noise (Satellite Passes)		
At 1 Pe	3ns	1.5ns (with 3 nsec pulse)
At 30 Pe	-	.3ns



BIN WIDTH IS   0.08 METERS.

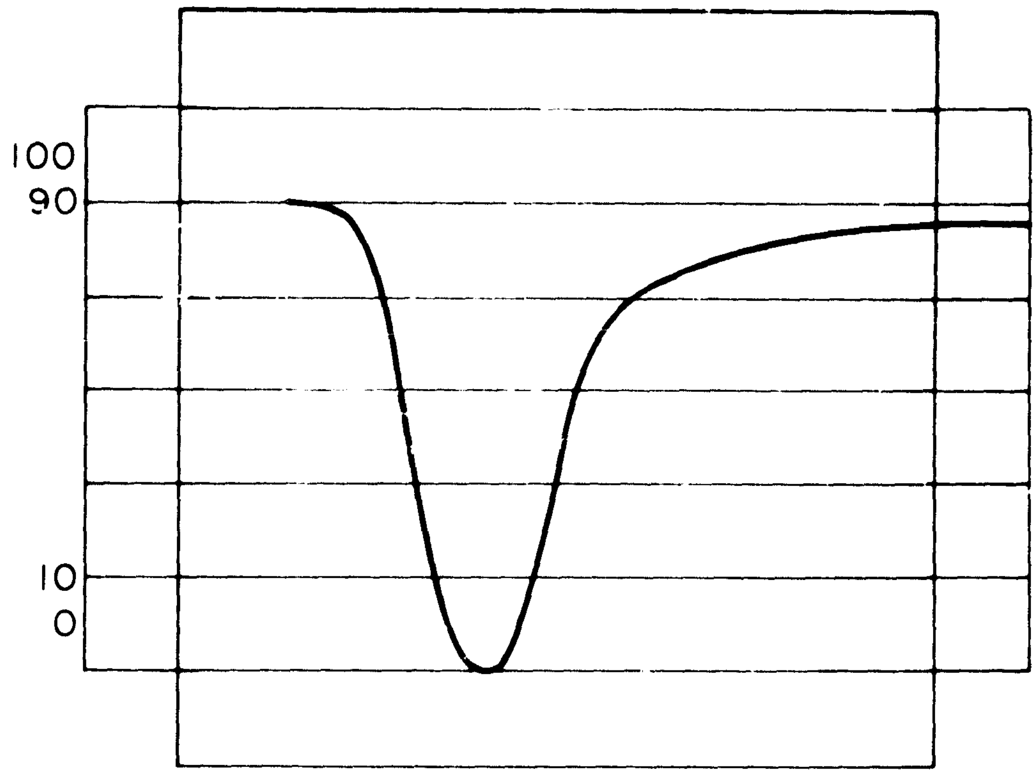
```
* * * * * * * * * * * * * * * * * * * * * * * *
* SITE 7921         SATELLITE 7603901          *
* DATE  82  1 21    TIME       1 42  6.019     *
*   99 POINTS   85 ACCEPTED   14 REJECTED      *
*  NOISE  SIGMA =   0.358 RMS =   0.353        *
*  TIME  OFFSET =     -1.380 +OR-   0.035 MSEC*
*  RANGE OFFSET =     -0.945 +OR-   0.046 M.   *
*  CORRELATION COEFFICIENT =    0.543          *
* * * * * * * * * * * * * * * * * * * * * * * *
```

Smithsonian Astrophysical Observatory

Figure 11.

Figure 12.

LASER OUTPUT PULSE
MT HOPKINS NOV 1981



FWHA 3.3 nsec
AMPLIFIER DETECTOR
3 nsec BLUMLEIN

11 FUTURE OF THE MT. HOPKINS AND NATAL LASER STATIONS

11.1 Mt. Hopkins Station

During 1981, the Mt. Hopkins laser was used as a test bed for the development of the laser upgrade. The station will continue in this capacity into early 1982 until the test program is completed, and then close. The equipment will be stored in a manner that will permit reactivation or relocation should it be desirable.

11.2 Natal Station

In response to NASA direction, the Natal laser operation was closed on 30 September 1981. The laser equipment was packed and is now on route to SAO. The local staff has been released and the U.S. Observers have returned to the U.S.

Discussions have been underway with NASA, SAO and representatives of the Italian National Space Council (a part of the CNR) for the relocation of this laser to Italy. Under an agreement now in draft, the laser would be relocated to a mutually-agreed upon site at CNR expense and they would take responsibility for operations. SAO would provide headquarters support, configuration control, and network integration and coordination. We anticipate a positive response from the CNR in early 1982 with operations commencing sometime late in CY1982.

12. PERSONNEL

12.1 Travel

Throughout the reporting period, various members of headquarters staff attended the weekly Crustal Dynamics Network meetings at Goddard Space Flight Center. Those most commonly present were Dr. Michael R. Pearlman and Mssrs. Latimer, Maddox and Thorp.

In mid-September, Mr. Jakob Wohn, our laser engineer, travelled to Mt. Hopkins to conduct field tests in support of the upgrading of the laser system. He was later joined by Mr. Noel Lanham, an electronics engineer, and both spent several weeks working on engineering aspects of the upgrading program.

In October, Mr. Edward Imbier, our Timing Engineer, visited U. S. Coast Guard Headquarters to review Omega transmitter site timekeeping. In December, he attended the Precise Time and Time Interval Applications and Planning Meetings at NRL, Washington, D.C.

The Fourth International Workshop on Laser Ranging Instrumentation was sponsored by COSPAR and the International Association of Geodesy at the University of Texas in Austin during the month of October, 1981. Dr. Pearlman, and Mssrs. Latimer and Wohn were asked to speak at several of the sessions held during the week long conference. The five papers presented at the Workshop were entitled as follows: SAO Calibration Techniques, A Review of Network Data Handling, An Evaluation and Upgrading of the SAO Prediction Technique, The Current Status and Upgrading of the SAO Laser Ranging System, and Some Current Issues in Satellite Laser Ranging.

Ms. Margaret Warner travelled to the Smithsonian Institution Foreign Currency Office to meet with Ms. Francine Berkowitz and Mrs. Betty Wingfield for administrative discussions concerning foreign currency programs in Egypt, India and Poland.

12.2 Visitors

Mr. Thomas Fischetti, Chief, Geodynamics Branch, and Mr. David Townley, Technical Monitor for the Satellite Tracking Network grant, both of NASA, visited Cambridge on 28 September for technical and programmatic discussions.

Dr. Andrew Adelman, Head, Laser Project Office of Network Operations and Planning Office at Goddard Space Flight Center, visited headquarters for administrative and technical discussions.

Dr. Ben Greene and Mr. Robert Bryant, both from the Division of National Mapping Laser staff in Australia, met with members of headquarters staff for discussions of laser ranging and on the status of NATMAP's development of satellite ranging and timing systems.

Dr. George Vei Professor of Geodesy at the National Technical University in Athens, Greece, and Dr. Yoshihide Kozai, Director of the Tokyo Astronomical Observatory in Japan, both visited headquarters during the month of October. Each met with our technical, data processing and operations personnel for discussions of laser ranging systems hardware and software

Dr. Weneda Dobaczewska and Dr. Janusz Zielinski, both from the Polish Academy of Sciences Space Research Centre (PASSRC), visited headquarters to discuss an ongoing cooperative project sponsored by the Smithsonian Foreign Currency and PASSRC. It is anticipated that Dr. Kolaczek, of PASSRC, and Dr. Colombo, of the SAO scientific staff, will work on a proposed cooperative program for Polar Motion Analysis.

Professor Luciano Guerriero, Director of the Italian National Space Commission visited SAO in the end of October. He was accompanied by Prof. Buongiorno. Initial plans were made for the proposed relocation of the Natal, Brazil laser system to a mutually agreeable site in Italy for operation in the global geodynamic observation program.

12.3 Personnel

Mr. Donald Andrews, an observer stationed in Peru, resigned from his position at the beginning of July.

Mr. Ed Imbier transferred from his position of Timing Engineer, STADAD, to work primarily for the Central Engineering department within the Observatory on October 18th.

Ms. Andrea Bowers was hired as a clerk-typist early in July. She resigned in early September.

Due to budgetary restrictions within the program, we were forced to close out our station Natal, Brazil at the onset of the new fiscal year. All of the local Brazilian employees were terminated from their positions during the month of September. Mssrs. Donald Patterson and Dana Seaman both arrived back in Cambridge for temporary assignments before leaving for Mt. Hopkins to work on the laser upgrading.

Also, Mr. Robert Borum, Communications Manager, left his position after having served 24 years at the Observatory.

References

Latimer, J. H., D. M. Hills, S. D. Vrtilek, A. Chaiken, D. A. Arnold and M. R. Pearlman, An Evaluation and Upgrading of the SAO Prediction Techniques. Presented at the Fourth International Workshop on Laser Ranging Instrumentation in Austin, Texas, October 1981.

APPENDIX A

STUDY OF THE TIME EVOLUTION

OF THE LITHOSPHERE

Grant NAG 5-150

Semi-Annual Progress Report No. 1

For the period 1 March through 31 August 1981

Principal Investigator

Dr. Micheline C. Roufosse

Prepared for
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

November 1981

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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Cambridge, Massachusetts 02138

NASA SEMI-ANNUAL REPORT 1
March 1 - August 31, 1981
Micheline C. Roufosse

The work performed during this reporting period falls into three categories.

1. A three-dimensional geoid of all oceanic regions has been obtained in collaboration with Dr. B. Parsons (M.I.T.) and Dr. D. Mckenzie (University of Cambridge, U.K.). To construct that geoid, we have used the first data set derived from the GEOS-3 radar altimeter and we have applied the corrections for bias and trend calculated by Dr. R. Rapp (Ohio State University). We have further removed from the data the long wavelengths (>4000km) by subtracting a reference geoid of degree and order 10 and the very short wavelengths (<100km) by filtering with a Gaussian filter. The filtered values are finally projected onto a square mesh and these grid values are machine contoured. Results obtained in the Pacific Ocean for both geoid and bathymetry (McKenzie, Watts, Parsons and Roufosse, Nature, 288, 442, 1980) can be seen in Figure 1. That work has enabled us to obtain a very detailed geoid over most oceanic areas and has identified quite clearly the areas that will be the best candidates for future investigation with both the SEASAT and GEOS-3 data sets. Among those, we have selected the South West Atlantic Ocean for which very little data has been collected during the GEOS-3 experiment.

2. We have recently received the complete SEASAT Geophysical data set and we have presently almost completed its editing and organization.

Several criteria have been used to edit the data: all data points of geoid heights larger than +/- 150 m have been rejected as well as all geoid heights which differed by more than 15 m from the 3 preceding and 3 following points. Furthermore, several passes have been chosen at random and the observed and calculated geoids have been plotted (see Figures 2 and 3) to check the efficacy of the rejection criteria and to strengthen them if necessary. So far, the data have proven to be of excellent quality except at the borderline between continents and oceans.

In order to obtain data files of manageable size we have divided the oceans of the world into 7 regions as follows:

North Atlantic Ocean

South Atlantic Ocean

Indian Ocean

North Pacific Ocean I and II

South Pacific Ocean I and II

Each satellite pass has been divided into these 7 regions. Within each area, all the files are organized by increasing revolution number and for each file, we provide the following information: latitude, longitude, standard deviation, observed geoid, reference geoid (up to degree and order 10), residual geoid and the position along pass in each region. The data will thus be in a format compatible with that used for GEOS-3 and will permit simultaneous use of the two data sets.

The data have not as yet been adjusted into a coherent network for bias and trend corrections, but the crossover errors observed so far are at the 60 cm level. When these corrections for bias and trend become available, we shall use them.

3. We have then selected from the South Atlantic Ocean region obtained for the SEASAT experiment a subset of the data in the geographical area located between 25 and 35 degrees South and between 320 and 335 degrees East, around the Rio Grande Rise. That area is of particular interest to us because it was created concomitantly with the Walvis Ridge, on the Mid-Atlantic Ridge; these two features have now moved away from the ridge because of the plate motion. The Walvis Ridge is presently located on the East and the Rio Grande Rise on the West of the Mid-Atlantic Ridge. The Walvis Ridge has been studied extensively using the GEOS-3 data (Roufosse, in preparation) and has been found to consist of three segments formed at different periods by a migrating hot spot. Preliminary results obtained over the Rio Grande Rise using the few available GEOS-3 data indicate that the geoid signals in that area resemble those obtained over the Eastern section of the Walvis Ridge and thus we tentatively conclude that these two features should have been formed simultaneously. However, because of the poor coverage available so far (2 Geos-3 satellite passes), we are in the process of further investigating that area using the SEASAT data. So far, 6 SEASAT passes have been retrieved and their interpretation will be the object of our future work.

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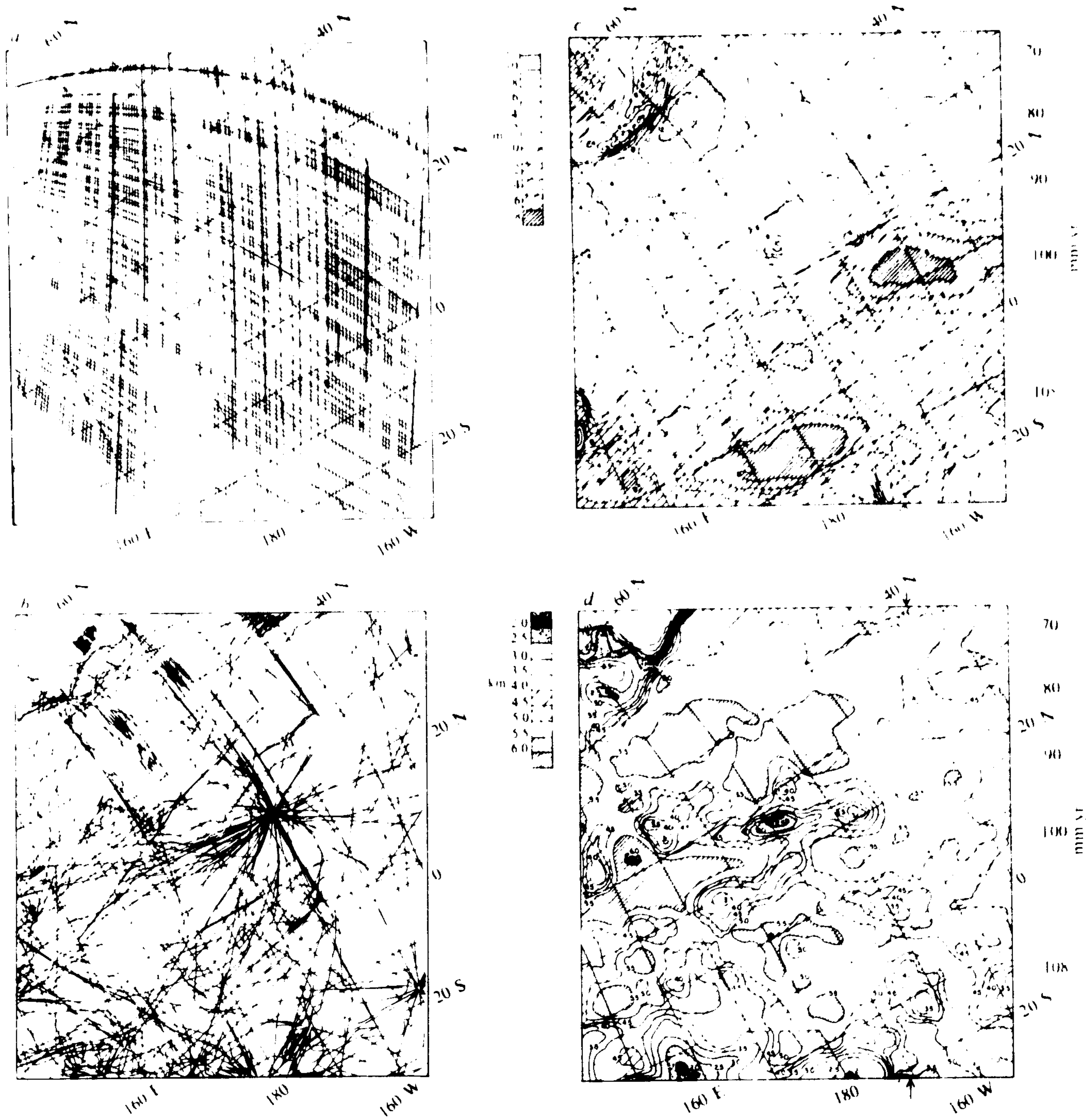


Fig. 1 Satellite altimeter (*a*) and ship (*b*) tracks used to obtain contour maps of geoid (*c*) and bathymetry (*d*) in the North and Central Pacific. The projection is an oblique mercator projection with axis 61.7°N, −82.8°E. Contour intervals are 2 m for (*c*) and 0.5 km for (*d*). The grid spacing in both cases is 100 km at the equator of the projection, and the gaussian half width for interpolation is 110 km for (*c*), 150 km for (*d*). The velocities shown on the right of (*c*) are those of the Pacific plate, moving from right to left, relative to the hot spot frame[15], and is 108 mm yr^{-1} at the equator of the projection

Figure 2.

Observed and calculated geoid heights using SEASAT data, reduction number 954.

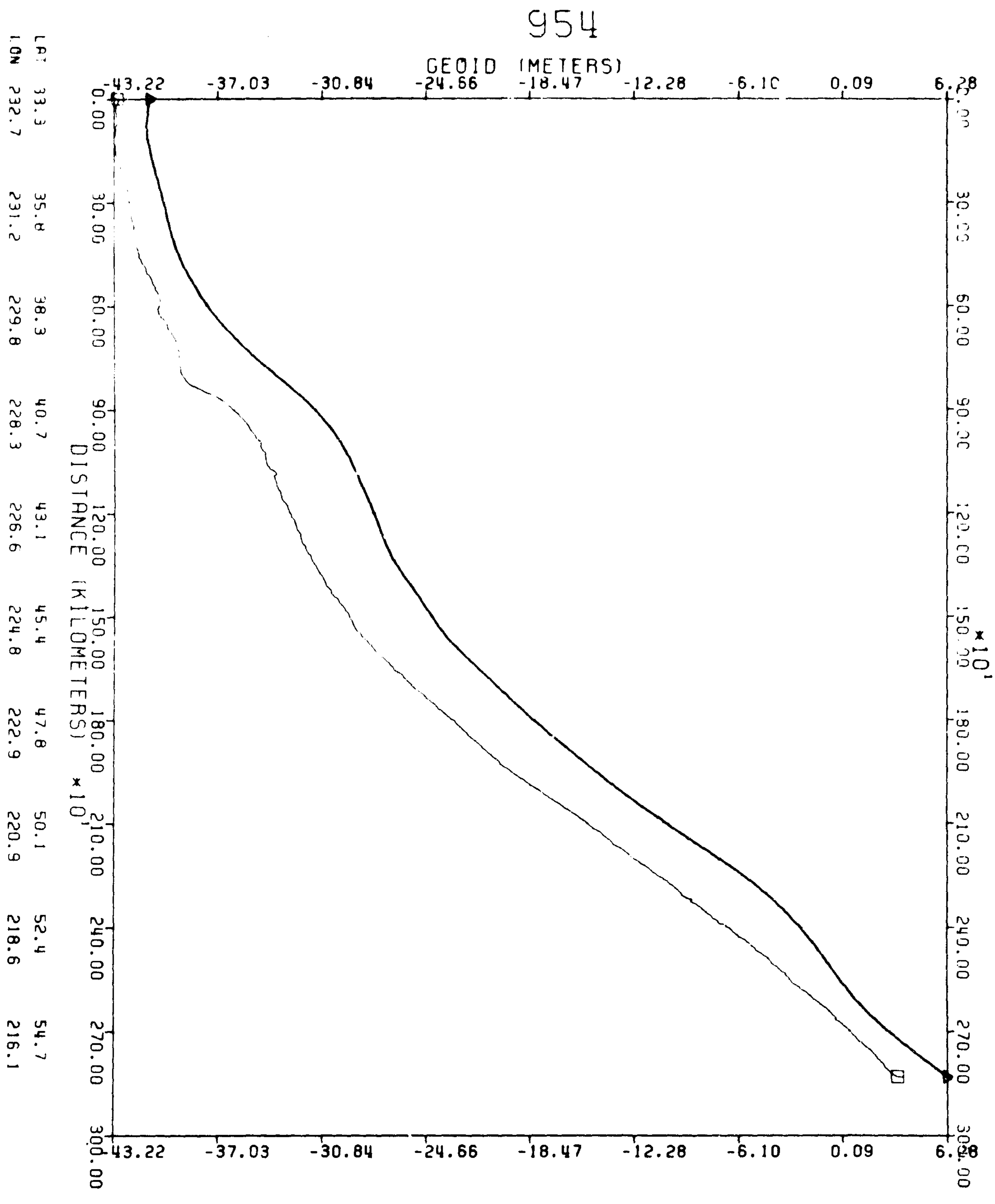
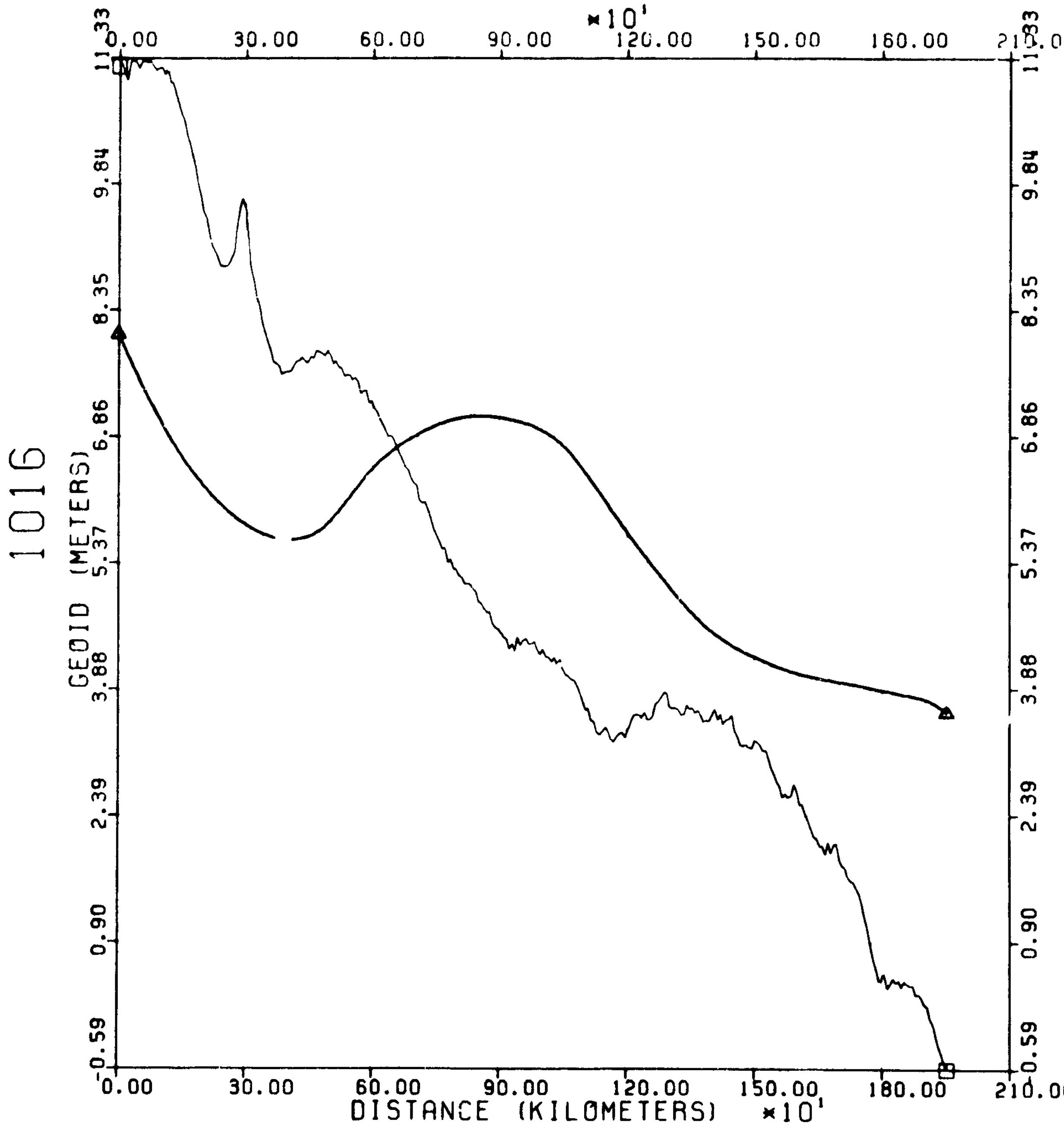


Figure 3.
Observed and calculated geoid heights using SEASAT data, reduction number 1016.



LAT	-31.0	-33.5	-35.9	-38.4	-40.8	-43.2	-45.5
LON	284.3	282.9	281.6	280.1	278.6	276.9	275.1

APPENDIX B

DEVELOPMENT OF IMPROVED

MODELS OF THE THERMOSPHERE AND EXOSPHERE

Quarterly Progress Report No. 3

For the period 1 October 1981 through 31 December 1981

Contract F19628-81-K-0033

Principal Investigator

Mr. Jack W. Slowey

March 1982

This report is intended only for the
Internal Management use of the Contractor and the Air Force

Prepared for

Air Force Geophysics Laboratory
Hanscom Air Force Base, Massachusetts 02731

Prepared by

Smithsonian Institution
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1. Introduction

Work under this contract is directed toward the development of improved models of the temperature, density, and composition of the earth's thermosphere and exosphere. The major emphasis at present is on the large spatial and temporal variations in these quantities that are associated with geomagnetic disturbance. The particular work in progress involves the analysis of a large body of mass-spectrometer data to determine the time lag between a geomagnetic disturbance and its atmospheric counterpart and the variations of the time lag over the globe. This work is the subject of this report.

2. Scientific Progress

Analysis of the ESRO 4 mass spectrometer data to better determine the time lag in the geomagnetic variation was continued. Specifically, a detailed study of individual events in which sudden increases in density occurred was begun. In this, it was decided to use the AE index rather than the K_p index. Accordingly, the 1-hourly means of the AE index over most of the lifetime of the ESRO 4 experiment were transcribed onto our computer (indices for the last 4 months, though available, have not yet been transcribed). These data cover an interval of 13 months, or almost 400 days, of the lifetime. In this interval, 28 intervals of 2 or 3 days in which there were one or more instances of sudden increase were selected for detailed study. Since each of these intervals contains data from both the upleg and downleg of the orbit at the particular height of 280 km, the number of potential instances where the time lag may be determined is doubled, though it is clear that not all of these will prove to be useful.

In our earlier model of the geomagnetic variation, the time lag was taken to be 0.1 day at the magnetic pole and to increase to 0.3 day at the equator. Several investigators have, however, indicated the time lag to be considerably shorter. The present study seems to confirm a much shorter time lag. This and some other preliminary results of our analysis, all applicable to a height of 280 km and in respect to comparison with the AE index are:

1. There is no perceptible time lag in high latitudes. The time lag at the equator is only 3-4 hours.

2. At the equator, where the number densities of all constituents increases in nearly the same proportion, the different constituents all maximize at the same time. In higher latitudes, where the relative composition is disturbed, there is evidence that the effect on the higher constituents may occur later than it does on the heavier ones.

3. Though the data are limited, no dependence of the time lag on local time is observed at the equator. Whether such a dependence can be observed in higher latitudes remains to be seen.

4. There are marked differences in the response of the atmosphere to increases of the AE index of a particular amplitude. It is not yet clear whether or not these differences can be reconciled with differences in latitude and local time or longitude.

3. Future Plans

We plan to complete the detailed study of individual disturbances in the ESRO 4 data that was discussed in the preceding section. It will then be necessary to reconcile the results of the study in terms of the more commonly used K_p index and the possible importance of other indices. The added insight gained in the study may also lead to a further attempt to study the time lag by statistical means and the possible development of a complete model of the geomagnetic variation based on the AE or other indices. Most importantly, we plan to extend our study of the time lag and related questions to data from other heights. A considerable amount of data from the Atmosphere Explorer (AE) experiments is now available on the computer at SAO. We also have a pending request to NASA for all of the available data from the AE-C satellite that we expect to be fulfilled soon.

4. No research failed during this reporting period.

5. No papers were submitted or published during this reporting period.

6. Professor Max Roemer of Bonn University visited the Contractor's facility in October to discuss plans for the Workshop to be held at the coming COSPAR meeting to consider proposed revisions of CIRA.

7. Mr. Slowey attended the workshop devoted to thermospheric dynamics that was held at GSFC in October. He has also been invited to present a review paper on the geomagnetic variation at a workshop on drag forecasting to be sponsored by NOAA in March.

8. No personnel charges or important administrative action took place during the reporting period.

9. <u>Fiscal Information</u>

Of the total funding of $67,000 authorized for the research about $33,719 has been expended as of 31 December 1981. About 50% of the work is complete. The total contract value of the work is about $128,000 for the period 1 April 1981 through 31 March 1984.

10. Cost Data

Cumulative Cost Data as of 31 December 1981

Labor Elements	Planned Labor Hours	Amount	Actual Labor Hours	Amount
Project Scientist	958	$ 23,562	896	$ 21,780
Programming/Data Handling	-	-	-	-
Other	8	67	2	18
Total Labor	966	$ 23,629	898	$ 21,798
Other Expenses				
Material and Miscellaneous		$ 2,895		$ 3,513
Computer		-		-
Travel		570		429
Total Other Expenses		$ 3,465		$ 3,942
Total Direct Cost		27,094		25,740
Indirect Cost		8,399		7,979
Total Cost		$ 35,493		$ 33,719

11. Planning Estimate as of 31 December 1981

Reporting Period

	Actual 4/1/81 to 9/30/81		Actual 10/1/81 to 12/31/81		Actual 1/1/82 to 3/31/82		Planned 4/1/82 to 9/30/82	
Planned percentage of technical completion	36%		50%		75%		100%	
Labor Elements	Hrs.	Amt.	Hrs.	Amt.	Hrs.	Amt.	Hrs.	Amt.
Project Scientist	710	$16,252	186	$ 5,528	424	$11,833	403	$11,249
Programming/Data	-	-	-	-	-	-	-	-
Other	3	29	(1)	(11)	4	36	32	288
Total Labor	713	$16,281	185	$ 5,517	428	$11,869	435	$11,537
Other Expenses								
Material and Miscellaneous		$ 2,089		$ 1,424		$ 1,000		$ 1,000
Computer		-		-		-		-
Travel		-		429		-		-
Total Other Expenses		$ 2,089		$ 1,853		$ 1,000		$ 1,000
Total Direct Cost		$18,370		$ 7,370		$12,869		$12,537
Indirect Cost		5,694		2,285		3,989		3,886
Grand Total		$24,064		$ 9,655		$16,858		$16,423

12. No property or equipment was acquired or developed during this reporting period.

13. No difficulties were encountered during this reporting period.

APPENDIX C

DEVELOPMENT OF IMPROVED

MODELS OF THE THERMOSPHERE AND EXOSPHERE

Quarterly Progress Report No. 2

For the period 1 July 1981 through 30 September 1981

Contract F19628-81-K-0033

Principal Investigator

Mr. Jack W. Slowey

January 1982

This report is intended only for the
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Work under this contract is directed toward the development of improved models of the temperature, density, and composition of the earth's thermosphere and exosphere. The major emphasis at present is on the large spatial and temporal variations in these quantities that are associated with geomagnetic disturbance. The particular work in progress involves the analysis of a large body of mass-spectrometer data to determine the time lag between a geomagnetic disturbance and its atmospheric counterpart and the variations of the time lag over the globe. This work is the subject of this report.

2. Scientific Progress

A statistical study to determine the time delay between a geomagnetic disturbance and the corresponding thermospheric disturbance was continued. This work is being done using mass spectrometer data at 280 km from the ESRO 4 satellite in comparison with the 3-hourly K_p geomagnetic index. As previously reported, we first attempted to determine the time delay by computing daily means of the total atmospheric density and taking the ratios of each daily value to that of the preceding day. The time delay was determined by fitting a model that related the density to both the mean K_p index for the day and that for the preceding day. The method had the advantage that it isolated the geomagnetic variation from the various other atmospheric variations. The disadvantage was that only mean values with respect to local time could be determined as a function of geomagnetic latitude.

The results of this first attempt were, nonetheless, rather interesting. The time delays that were determined were systematically larger at all latitudes that what was expected from earlier work on individual disturbance events. Most surprising was an apparent minimum in middle latitude, with a return to larger values in high latitudes.

In order to resolve the dependence of the time delay on local time, two attempts were made to use the individual ESRO 4 density measurements in determinations of the time delay. In the first of these, the method was similar to that used with the daily means. In this case, ratios of the density at 280 km from each orbit to the corresponding value from the preceding orbit were taken. A model was then fitted to the data in a particular bin for each one of 12 assumed time delays in one-hour steps between one and twelve hours, the object being to establish which time delay gave the greatest correlation between the density ratios and the corresponding changes in the geomagnetic index. The second attempt was similar to the first in that a model was fitted for each of twelve assumed time delays. Here, however,

the model was fitted to residuals obtained by subtracting the quiet-time values obtained from a spherical harmonic model fitted specifically to the ESRO 4 data.

These attempts to obtain better resolution of the time delay both failed to produce acceptable results. There are several factors, all relating to the nature of the K_p index, that are thought to have contributed to this. To begin with, of course, the K_p index is not necessarily a direct measure of the specific processes that cause the atmospheric disturbance. Also, it is a global index and does not precisely reflect the onset of disturbance. Finally, the temporal resolution of the K_p index is only three hours. This is clearly inadequate where we are dealing with what are essentially instantaneous values of the observed densities. Of course, the results of our analyses would undoubtedly have been more meaningful if we had smoothed the observed densities to agree with the smoothing of the K_p index. We could, for example, have combined the observed densities from three successive orbits and given half-weight to the end values, producing a rough equivalent of three-hourly means. Even if we agree to the suitability of such a procedure, however, we would be making a very significant concession as far as temporal resolution is concerned. Perhaps a better approach would be to substitute another index, such as the AE index. The AE index is assumed to be a measure of the overall activity in the eastward and westward auroral electrojets and is correlated with thermospheric disturbance in the same way that the K_p index is. Most importantly, it is available with much greater resolution. Averages of the AE index over one hour have been published in tabular form and values at 2.5 minute intervals are available on computer tape for the time covered by the ESRO 4 data.

3. Future Plans

We plan to continue the current statistical study of the time delay in the geomagnetic variation with a view not only to improving our knowledge of its variations with latitude but to resolve its variation with local time as well. We will probably make a further attempt using the K_p index, introducing a smoothing in the observed densities as mentioned above. We will further investigate the possible uses of the AE index, starting with the one-hourly averages, and will continue to examine the other available indices with respect to their use in determining the time delay. As mentioned in our previous report, we will also undertake a systematic study of the time lag as determined from individual disturbances. This will serve to illustrate and check the results obtained from the statistical analyses. Also as mentioned previously, we plan to extend our work on the geomagnetic variation to data from other heights. To this end we are continuing to pursue acquisition of data from the Atmosphere Explorer satellites.

4. Some of the research undertaken during this period failed in part - see item 2.

5. No papers were submitted or published during this reporting period.

6. No persons visited the contractor's facility in connections with the contract effort.

7. No travel was necessitated by the contract.

8. No personnel changes or important administrative action took place during the reporting period.

9. Fiscal Information

Of the total funding of $24,000 authorized for the research for the period 1 April through 30 September 1981, $24,000 was expended as of 30 September. This phase of the work is complete. The total contract value of the work is $128,000 for the period 1 April 1981 through 31 March 1984.

10. Cost Data

Cumulative Cost Data as of 30 September 1981

Labor Elements	Planned Labor Hours	Planned Amount	Actual Labor Hours	Actual Amount
Project Scientist	692	$ 16,186	710	$ 16,252
Programming/Data Handling	-	-	-	-
Other	6	42	3	29
Total Labor	698	$ 16,228	713	$ 16,281
Other Expenses				
Material and Miscellaneous		$ 2,093		$ 2,089
Computer		-		-
Travel		-		-
Total Other Expenses		$ 2,093		$ 2,089
Total Direct Cost		18,321		18,370
Indirect Cost		5,679		5,694
Total Cost		$24,000		$24,064

11. Planning Estimate as of 30 September 1981

	Reporting Period							
	Actual 4/1/81 to 6/30/81		Actual 7/1/81 to 9/30/81		Planned 10/1/81 to 12/31/81		Planned 1/1/82 to 9/30/82	
Planned percentage of technical completion	22%		36%		53%		100%	
Labor Elements	Hrs.	Amt.	Hrs.	Amt.	Hrs.	Amt.	Hrs.	Amt.
Project Scientist	432	$ 10,215	278	$ 6,037	266	$ 7,376	618	$ 17,247
Programming/Data	-	-	-	-	-	-	261	3,635
Other	1	7	2	22	2	25	52	700
Total Labor	433	$ 10,222	280	$ 6,059	268	$ 7,401	931	$ 21,582
Other Expenses								
Material and Miscellaneous		$ 1,313		$ 776		$ 802		$ 2,420
Computer								
Travel						570		
Total Other Expenses		$ 1,313		$ 776		$ 1,372		$ 2,420
Total Direct Cost		$ 11,535		$ 6,835		$ 8,773		$ 24,002
Indirect Cost		3,575		2,119		2,720		7,441
Grand Total		$ 15,110		$ 8,954		$ 11,493		$ 31,443

C-2

12. No property or equipment was acquired or developed during this reporting period.

13. No difficulties were encountered during this reporting period.